AD-A058 114 GENERAL ELECTRIC CO PHILADELPHIA PA RE-ENTRY AND ENV--ETC F/G 20/1
ENVIRONMENT VARIABILITY IN THE DEEP SOUND CHANNEL.(U)
MAY 77 E J SOFTLEY, M J ENGEL N00014-73-C-0030
UNCLASSIFIED 77SDR2315 NL

1 OF 2
AD
A058 114

LEVEL II

12

GE Document No. 77SDR2315

ENVIRONMENT VARIABILITY IN THE DEEP SOUND CHANNEL

Eric J. Softley
M. J. Engel

May 1977

This Research Was Sponsored By The Office Of Naval Research
Under Contract No. N00014-73-C-0030

GENERAL ELECTRIC
Re-entry & Environmental
Systems Division
3198 Chestnut St., Philadelphia, Pa. 19101

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 14 GE Document No. 77SDR2315
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): 6 Environment Variability in the Deep Sound Channel.
5. TYPE OF REPORT & PERIOD COVERED: 9 Final Rep[redacted]. 1972 - 1976.
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): E. J. Softley, M. J. Engel
8. CONTRACT OR GRANT NUMBER(s): 15 N00014-73-C-0030
9. PERFORMING ORGANIZATION NAME AND ADDRESS: General Electric Company, Re-entry and Environmental Systems Division, Philadelphia, Pennsylvania 19101
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
11. CONTROLLING OFFICE NAME AND ADDRESS: Office of Naval Research Code 222, 800 No. Quincy Street, Arlington, Virginia 22217
12. REPORT DATE: 11 May [redacted]77
13. NUMBER OF PAGES: 171
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Air Force Plant Representative Office, GE-RESD and SD, P. O. Box 8555, Philadelphia, Pa. 19101
15. SECURITY CLASS. (of this report):

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report): Unlimited 10 Eric J. / Softley M. J. / Engel
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report): Reproduction in whole or part is permitted for any purpose of the United States Government.
18. SUPPLEMENTARY NOTES: 12 152 p.
19. KEY WORDS (Continue on reverse side if necessary and identify by block number): Ocean temperature measurements, deep ocean moorings, Sea Robin buoy, SNAP-21 (RPG), radioisotope power generator, thermistor string, nylon rope characteristics, two-element taut mooring.
20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Deep ocean moored thermistor string buoys were constructed to obtain vertical temperature profiles at depths down to 1500 meters. A requirement for data acquisition in near real time was met by means of on-board signal conditioning and prompt radio transmission to a computer equipped shore station for automatic processing and subsequent use in relating acoustic propagation to temporal variations along designated acoustic paths.

78 08 23 057

DD FORM 1473, 1 JAN 73 — EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

404 884

Two such buoy systems were launched. One was successfully implanted in about 4800 meters of water providing some 1000 hours of real time on-station temperature, environmental and housekeeping data while the second was lost during the final stage of deployment. A complete description of the equipment along with design considerations and techniques utilized is appended.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the efforts of the many people who assisted in this activity. They include Dr. Alex Pavlak and Dr. Roger Hoppmann, who contributed to the analyses; David Rogers, who designed all the electronics; Mark Jaffe, who programmed all the computers; Ralph Buonomo, Ron Gorsky and Robert Pridgen, who contributed both ashore and afloat and James Rooney who smoothed financial waters. We also wish to thank Pat Paterson, Jack Kluener, Gerald Canuta and the other crew members of the R.V. Venture. Finally we wish to recognize the support of John Gregory (ONR) for stimulating technical discussions during the program. Last, but certainly not least, we wish to thank Dr. Alan Sykes for his patient support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont)

1.0 INTRODUCTION

The propagation of low frequency sound in the ocean has long been recognized as dependent on the nature of the deep sound channel. This channel allows the existence of fully refractive ray paths with an absence of losses from surface interaction. It has also been recognized that this propagation is not steady but highly time dependent, and that temporal as well as spatial variations in the environment are important contributors to the amplitude and phase of received signals.

For many years programs to examine and characterize this have been sponsored by the U.S. Navy. One such program which features fixed source and receivers has concentrated on propagation across the straits of Florida [1, 2] and since 1971, in the North America Atlantic Basin.[3] Supported by ONR the Institute for Acoustic Research (IAR) has operated an acoustic projector off Eleuthera with received signals recorded in Bermuda and at other sites. The General Electric Company's Ocean Sciences Laboratory (GE-OSL) contributed to the program with environmental measurements in the vicinity of the sound source. This report discusses that work.

1.1 Environmental Data Requirements

The problem in relating acoustic propagation changes to environmental changes is the immensity of the problem. Accurate measurement is neither easy nor cheap and the area is large. A deterministic conclusion may be feasible for short paths and where the nature of the fluctuation is simple. A statistical correlation seemed more likely to be successful. Since the sound speed variations, whose fluctuations are almost a single parametric function cause changes in the acoustic path, and thus multipath interference, these variations were the center of attention. Hence a plan was developed to measure temporal variations in the temperature profile at a number of locations along the Eleuthera-Bermuda path, to examine the nature and source of these fluctuations in time and space, and to relate to the acoustic signals during that time period. The measurement facilities were moored buoys with near vertical temperature measuring arrays. Figure 1 shows the plan for such buoys. Initially data would be obtained near the source with progressive deployments toward Bermuda. A requirement of the program was that these buoys telemeter and process the data in near real time. This necessitated a surface buoy with telemetry of the data.

Figure 2 shows the paths of fully refracted rays in the vicinity of the sound source. (These rays were computed by a GE-OSL computer program (BART) and compared to the FACT model.) Refraction of the rays can be divided into two vertical subdivisions. Above the axis where the sound speed is a minimum and taken to be at 1500 m per the thermistor location, the variation is primarily due to the temperature gradient in the permanent thermocline. Below the axis it is primarily pressure dependent with small fluctuations in the temperature profile. Hence temperature fluctuations above 1500 m were needed.

Figure 2 also shows the location of the first two buoys. If temperatures above 1500 meters only are considered, the first zone where these fluctuations directly affect the acoustic rays is a region up to 5 n. miles offshore from the source with an optimum of around 3 n. miles. The second buoy's location was chosen at 33 n. miles in the second influence zone. The separation of 30 n. miles seemed excellent for correlation between the buoys.

The accuracy of the measurement required was determined as being equivalent to 0.1 m/sec. in sound speed variation. This was not overdemanding and the final resolution was a factor of 5 more sensitive.

The nature of the phenomena which contribute to the temperature fluctuations is varied. Primary interest was in diurnal and semi-diurnal variations which had been observed in the acoustic phase data. However, internal waves of shorter duration also were of interest, as were eddies and other large space-time scale ocean processes. Hence an experiment duration of many months was desired and with sampling time a few minutes. Eventually a 12 minute interval was selected. However, because other intervals may be more desirable the ability to command from the buoy to shore was an added requirement.

The number and spacing of the sensors were more difficult. Practical considerations suggested that 12 sensors were possible and the corresponding spacing was 100 meters. The first buoy did use a string with 12 thermistors but it was possible to incorporate 18 into the larger diameter string of the second buoy. IAR suggested a concentration in the vicinity of the axis and this was done for the second buoy.

A summary of the requirements, as determined in discussions with IAR and ONR, were:

1. Temperature measurement to 1500 m with at least 12 sensors
2. Data Interval 12 minutes - commandable from shore
3. Data transmitted - to shore in real time
4. Experiment duration of many months
5. Temperature resolution better than $0.05^{o}C$

and these translated to:

6. Surface buoy with all weather capability
7. Integral sensor array and mooring system
8. Computerized shore station

The required buoy locations were chosen as in Figure 3. The original Sea Robin II became Sea Robin III for the site closer to shore. The second buoy, a new design, was denoted as Sea Robin IV.

1.2 Buoy Facility Capability

The preceding requirements were translated into the design of a buoy with a thermistor string mooring. This facility is described in Appendix A. Since a Sea Robin buoy existed at the time and was not in use this was the basis for the design.

The sensitivity of the temperature measuring device depended on the sensing element and its proximity to the environment. The device had to be stable so that long duration experiments could be performed. Thermistors were selected for several reasons. The inherent sensitivity was sufficient to allow resolution of better than $\pm 0.001^{o}C$. Long term drift was of the order of $0.02^{o}C$/year. Moreover, with direct current bias the signal level could be high enough that direct analog/digital conversion was possible. Thermistor beads were as small as 0.007 inches diameter and this allowed moulding thermistors into the cable without changing its diameter which would remain small.

A primary requirement for the thermistor string design was that the string be an integral part of the mooring. This was felt to be simpler than solving the entanglement problem associated with two vertical components.

Hence, the two-element taut moor presented in Figure 4 was being considered. The upper element being the thermistor string. The lower element would consist of nylon line with a combined scope* of less than one. This moor design provides a non-zero mooring tension under all load conditions. Loading of the thermistor cable was a function of the mooring geometry and environment conditions.

The nylon line was chosen to give optimum elasticity. Plaited line (Columbian Rope Company) had the elasticity of 3 ply with the significant advantage of near torque balance construction. A load elongation curve for the nylon similar to that shown in Figure 21 was used. The general design process is shown in Figure 5.

A typical Antilles current profile was originally used for design purposes.[4] A modified profile including wind driven shear currents (see Figure 6) was used for the final design.

Static and dynamic analyses were performed for Sea Robin III and later repeated for Sea Robin IV.[5] Examples of Sea Robin IV calculations are shown in Figures 7, 8 and 9.

As a result of these analyses the decision was made to develop and deploy Sea Robin thermistor string systems to meet the requirements stated in Section 1.1.

Section 2 of this report describes some of the events of this program and Section 3 describes some of the results. The Appendix details the hardware developed and used.

*Scope is defined as the ratio of length of the mooring line to the depth of the water.

2.0 PROGRAM HISTORY

The program, which started with the concept of a surface buoy, a thermistor string and a compliant mooring to obtain a desired near vertical taut configuration, endured through several phases leading to the successful implant and operation of Sea Robin IV. Many perturbations resulted in delays and program postponements among which was an unsuccessful early attempt at implant. A general chronology of events follows and some of the major items are detailed later.

2.1 General Chronology

As described earlier the original concept of the thermistor string mooring was derived during discussions with the University of Miami and the Office of Naval Research. The feasibility of the mooring along with preliminary calculations of its static and dynamic behavior was explored during the latter half of 1971. As a result a program to develop the thermistor string was undertaken during 1972. Sea Robin II, as it then existed, was to be used since it was available at no cost. However, since the reserve buoyancy was insufficient to allow satisfactory design of the mooring the original hull was lengthened and modified. Further, at the request of ONR, the original damper section shown in Figure A-15 of the Appendix was augmented to incorporate a special frame to hold a SNAP 21 radioisotopic power generator (RPG) which would supply the necessary operating power.

A new buoy electronics assembly was designed and built. A shore station was assembled using a PDP 8 computer as a base and using a surplus GE van for housing. This allowed for system checkout at GE-Valley Forge with early shipment to the Bahamas.

Early in 1973, as a result of difficulties between the U.S. and the Bahamas on the use of the AUTEC range and on an initial claim by the Bahamas of a 12 mile offshore territorial limit, the RPG was deemed too problematic and a new battery pack to replace it was created. This changed the weight and center of gravity of the buoy requiring new static and dynamic calculations. Also it had become apparent that a more exact knowledge of the nylon characteristics was extremely important and a nylon rope characterization program was started. The characterization was not completed until late in 1974.

Launch of Sea Robin III had been scheduled for early in 1973, but these program changes slipped the schedule to July 1973. In the interim a test mooring of a sample thermistor string was made off Miami in March-April 1973.

The launch of Sea Robin III was not successful, resulting in design changes to eliminate the failure modes. The currents were much higher than had been expected, thus the buoy was modified further to lighten it. A new mooring was constructed with anti-strumming fairing added. Some experiments on the effectiveness of this anti-strumming fairing were performed. The new mooring was completed early in 1974.

Meanwhile, new buoy systems, Sea Robin IV and V, were proposed. Their buoy hulls were to be substantially larger than Sea Robin III in order to increase safety margins for reserve buoyancy and cable loads. The three buoys, SR III, IV & V were to form a triangular array with the ability to correlate the data between any two buoys. Upon evaluation of this proposal, Sea Robin IV was designed, being completed in February of 1975. (Sea Robin V was dropped as the result of an ONR decision to fund an alternative buoy by IAR.)

The new buoy system also incorporated a faired thermistor string. Since the buoy was designed for use anyhwere along the Eleuthera - Bermuda sound path, switchable multiple frequencies (H.F.) were employed. The shore station at Eleuthera was modified to handle up to six such buoys with four selectable frequencies. New computer programming was developed and the shore station so implemented.

Early in 1975, the two buoys were put on test at Valley Forge with a new computer shore station simulator. This simulator was later incorporated into the system to monitor shore station operation from Valley Forge.

At the request of ONR Sea Robins III and IV were to be implanted in early 1975 essentially at the same time as the IAR buoy. The launch vessel for all buoys was to be the R.V. Pierce, owned and operated by Tracor Marine, Fort Lauderdale. Component delivery delays and fabrication problems caused the implant date to slip from July to November 1975. Then budgetary difficulties with Tracor caused a further slippage so that the Sea Robins were implanted in January 1976 while the IAR buoy was implanted in February 1976.

In the interim period the Sea Robin IV mooring was again modified to include a two-axis inclinometer at the thermistor string - nylon junction in the mooring which was intended to assist in determing thermistor depths. However, due to noise from the RPG the inclinometer data could not be used. Thus, the thermistor depths were determined from the mooring line tension as originally planned.

Sea Robin III was lost during implant. Sea Robin IV was launched successfully and obtained approximately 1000 hours of continuous temperature data. It was retrieved and returned to storage in Miami in April 1976.

Since that time a preliminary analysis of the data has been completed and detailed plots of temperature isotherms and sound speed have been prepared. The analysis should be continued with spectral evaluation and examination of the thermistor data to determine vertical correlation lengths, and to relate the correlation lengths to the time scales of the ocean processes.

2.2 Thermistor String Development

Reference 6 describes the thermistor string development in detail. A brief discussion is presented here. The thermistor cable was an integral part of the mooring system and was designed for loads up to, but not exceeding, the reserve buoyancy of the buoy. For a Sea Robin IV this meant cable loads up to 6000 lbs.

It was obvious that a load carrying member in the cable was necessary. This could have been chosen as a center strength member or external armor or both. If both are used, the balance of load is also variable. The options are shown in Table I. In the final analysis the cable was designed with 100% center strength member loading. However, for handling ease a constant cross section was desired and this allowed the option of adding armor after final thermistor insertion. Figure 10 shows a conceptual design of the cable.

The torque balanced, center strength member had a single remaining parameter, diameter. Increasing the diameter increased the total strength but also added to the size and weight of the final cable and to the buoy loading. The diameter was left as a parameter and carried through the interaction of stress analysis and mooring cable configuration selection. The analysis indicated that the structural member would be steel wire rope, 1/4 inch diameter for Sea Robin III and 3/8 inch for Sea Robin IV.

The number of conductors depended on the size of the center member and the size of the conductors. The conductors were chosen just large enough that the error due to the resistance of the conductor ($L \sim 10,000$ ft) was of order the resolution of the thermistor. Sea Robin III had a cable with 14 conductors (12 thermistors) while Sea Robin IV had 24 conductors (18 thermistors).

A wet thermistor cable design was selected. With this design the outer cable jacket did not need to provide a pressure seal. Rather, sea water was permitted to seep around the conductors and the insulation on each conductor served as a seal. It was therefore necessary to splice the thermistors into the conductors in such a manner that the conductor insulation remained continuous and provided adequate protection from seawater seepage under pressure.

Low density polyethylene was selected as a conductor insulation and potting plastic. Polyethylene has low water absorption characteristics and allows for easily controlled injection moulding techniques. Polypropylene was also evaluated and found to be unsuitable because of its high melting temperature and susceptibility to cracking.

Samples of spliced thermistors were pressure tested to 21,000 psi without insulation breakdown. Long time pressure tests at 6,000 psi were conducted. The thermistor characteristics were found to be very slightly pressure dependent. This pressure dependence was repeatable and was factored into the thermistor calibration.

Final calibration of the assembled string was made using a technique developed for the purpose. Final calibration accuracy was about 0.01°C.

2.3 Thermistor String Test (Miami)

Because of the unproven nature of the thermistor string, it was decided to deploy a short sample, containing 6 thermistors, in a test mooring. To minimize cost, a site close to Miami was desired and the site chosen was some 3 1/2 miles north of Fowey Rocks in about 200 meters of water. A Braincon plank-on-edge buoy was used (on loan from the University of Miami) with some rapidly assembled mooring hardware and electronics. Figure 11 shows a schematic of the mooring. The buoy was on station from March 19th until April 10, 1973, although for some of this time the buoy itself was below the surface. Calculations showed that this was to be expected since the buoy had little reserve buoyancy

and currents could be expected to fluctuate significantly. For example in the original clean configuration a current of a 2-1/2 knots would submerge the buoy. Attachment of seaweed or other bio-mass material could rapidly degrade its buoyancy capacity still further.

Recovery of the buoy and mooring was only partially successful since only the upper 40 meters of thermistor string were recovered. There were 3 thermistors in the recovered section.

Post recovery analysis of the thermistor string and hardware showed that all three thermistors and the cable itself were in excellent condition with no evidence of conductor fatigue. This was especially important because the implant personnel reported very strong strumming of the mooring. Strumming could also have accounted for the submergence of the buoy.

The navigational light, designed for use on the Sea Robins, had been seen clearly 6-1/2 n. miles away in Miami and was deemed satisfactory.

2.4 First Sea Robin III Deployment

An initial and unsuccessful attempt to launch Sea Robin III was made in July 1975. A two vessel implant was employed. The launch vessel was a modified LCT; the second vessel was a 36 foot Trojan with twin screws.

The actual launch was delayed by choppy seas and by difficulties with the support vessel which suffered some damage on a reef during its transit. On the launch day the weather again became extremely choppy but a decision against further delay was made under economic pressure.

Accordingly both vessels proceeded to the launch site at 0800. The buoy over-boarding procedure proved to be a very sensitive operation with little margin for error, thus, the launch proceeded slowly so that final anchor touchdown occurred around 1600 hours. At this point, while the anchor was still attached to the crown line, a visual inspection was made of the mooring attachment below the buoy hull. The strain relief assembly was seen to be severed and the thermistor string conductors irreparably damaged. Since there was insufficient daylight to retrieve the system and it was considered too dangerous to hang onto the mooring with the LCT overnight, the thermistor string was cut and the mooring jettisoned. The buoy

hull was retrieved. Speculatively, deployment loadings experienced by the buoy in that sea state proved too great for the buoy appendages to sustain.

Two useful observations had been made. First the Sea Robin III site was located in a strong southeasterly flow and not the northwesterly flowing Antilles current as expected. Secondly, the Sea Robin III mooring was strumming with apparently large amplitude.

As a result of this attempt several modifications to the system were made. A new implant would be attempted with the buoy redesigned to accept a sturdier, more flexible strain relief assembly and a more rugged antenna. A prelaunch survey was necessary to examine the currents and bottom topography. Finally anti-strumming fairing, although costly, was considered a necessary addition to minimize potential cable fatigue and to reduce cable drag.

2.5 Prelaunch Survey Voyage

During June 1975, a field trip was taken primarily to survey the Sea Robin III launch site. Examination of the charts and indications from the earlier launch attempt showed an extremely uneven bottom. To minimize cost the R.V. Rosette was used (see Appendix Fig. A-26). An acoustic bathymetry system was assembled. The acoustic transducers, 24 kHz narrow beam, were mounted into a "fish" assembly. The assembly was installed on the R.V. Rosette. Refer to the Appendix (A.5.2).

The base for the survey was Harbor Island on the northern tip of Eleuthera. On June 23rd the Sea Robin III site was surveyed in detail. Navigation was by Loran A. A DEC PDP 8 M computer was used to read and store the Loran A data from 2 channels as well as digitized data from the bathymetry. Several tracks were made over the site.

On June 24th a short rerun was made to check the repeatibility of the data. Then a long straight run from close to shore out to the Sea Robin IV site was made to examine boat drift. (Winds were quite light for the period, 5-10 knots S.E., except for a brief rain squall on June 25th.)

A repeat run on June 25th was made because of the results of the day earlier. XBT probes were dropped at intervals with the data recorded and stored in the computer. Finally another visit was made to the SR III site to confirm the reacquisition of the site using bathymetry.

Results of this survey are discussed later. However, visual sighting on shore and timing of the vessel tracks indicated that the 3L1 (Loran) lines were displaced from the location shown in the charts. It was decided that the same Loran A receiver and bathymetry would be used for the launch.

During the survey trip and while the shore station was manned, a power failure occurred in the station. Power supply, normally 115V, dropped to 50V and then increased to 150V. The resulting damage to the computer was extensive and a special mission to repair the equipment was necessary.

2.6 Implant Voyage For Sea Robins III & IV (January 1976)

2.6.1 Pre-Mobilization

Following a lack of success in negotiating an affordable price from Tracor for use of the G.W. Pierce, John Gregory (ONR) and Eric Softley (GE-OSL) visited Off-Shore Incorporated, Miami Beach, Florida, owners and operators of the research vessel Venture, to discuss the suitability and availability of their ship for use in the implantation. Upon determining that the ship was satisfactory in all respects, arrangements were made for an implant voyage commencing January 5th with some pre-mobilization work to take place before that date. In addition to the ship a large powered reel stand was needed for deployment of the mooring and a large powered winch, for the operation of the crown line which would be used for lowering the two anchors. The winch and corresponding hydraulic power pack were leased from Tracor. Because of the difficulty of mounting this winch on deck it was decided to take delivery of the equipment early on the 19th of December, so that this and other hardware installation could be done prior to January 5th. A stainless steel sheave was purchased from General Oceanics, Miami, with immediate delivery thanks to the cooperation of Shale Niskin (G.O.). Off-Shore, Inc. took responsibility for mounting the sheave together with a roller assembly on a frame that was designed during the visit. It was decided that the RPG would remain at Tracor until mobilization had commenced.

Arrangements were made with Commander Florwick, NOAA, to use dock space at Dodge Island, Miami for the loading of the hardware aboard the Venture. In addition, Cmdr. Florwick agreed to allow storage of two trailers loaded with Sea Robins III and IV at his facility which, in turn, allowed an immediate move of the trailers from their location at Tracor.

2.6.2 Mobilization

Following a final briefing on January 1st the GE transport van with necessary electronic gear aboard left from Valley Forge for Miami followed by the remainder of the GE crew on January 4th. Initial work at the NOAA dock was put off for 4 hours because of the delayed departure of two University of Miami research vessels. While waiting, the electronic equipment for navigation, bathymetry, acoustic release operation, communications and computation (PDP 8 computer) was loaded aboard the vessel. The ship was moved to the NOAA dock about 1300 hours on January 5th and loading started.

The Sea Robin III buoy hull was loaded on the upper (lifeboat) deck of the Venture, see Figure 12. The Sea Robin III mooring and anchor were placed in the hold of the vessel, below the foredeck. These items would be moved topside after the deployment of Sea Robin IV. (Due to the presence of the nuclear generator Sea Robin IV had to be deployed first.) The crown line was loaded aboard the powered reel stand which was used to back tension the wire while being loaded aboard the large winch. A tension of approximately 1000 pounds was achieved. In addition to the steel wire, approximately 750 feet of 1 inch diameter nylon was used at the lower end of the crown line. (The purpose of the nylon was to reduce dynamic loading on the steel wire due to ship heave and roll.)

At this point a test of the crown line winch was made by rigging the line through a tensiometer to a termination on the deck. Satisfactory control of the winch was obtained up to a measured line tension of 11,000 pounds. This was in excess of any required loading and did not represent the maximum capacity of the winch.

Acoustic communications for bathymetry and the release operation were made through a GE designed, rigidly mounted, fish. This fish contained directional hydrophones and transducers for operation of the AMF transponder and releases and two 24 kilohertz narrow beam transducers for bathymetry. The framework for this fish had been designed for mounting on the G.W. Pierce (Tracor). It was necessary to modify this frame considerably for accommodation by the Venture.

It was decided to run through, at the dock, the complete procedure for placement of the 8000 pound anchor over the side of the vessel. This represented by far the greatest danger during the implant and the additional time was felt to be an invaluable investment. The procedure was established, the anchor placed on board the vessel and the final staging of the Sea Robin IV buoy hull initiated.

The RPG was shipped from Tracor (Ft. Lauderdale) by a leased truck and staged with the Sea Robin IV hull and electronics on the dock, see Figure 13. It was found that an internal connection was missing from the RPG multi-pin connector. Fortunately, a remedy was made without removing the potting compound. The buoy electronics worked satisfactorily and Dave Rogers (GE-OSL) proceeded to Eleuthera to man the shore station. The buoy was loaded aboard the ship and connected to the computer to maintain an operational check on the system. Almost immediately the buoy ceased its timed operation. When the buoy RF module was removed it was found that the high frequency switching transients from the DC-DC converters in the RPG were resetting the interval timer in the buoy electronics. This was corrected by suitable filtering. The electronics were reinserted in the buoy and a continual operational check maintained using the onboard computer.

Departure from the NOAA dock was now planned for mid-day Saturday, January 10th, two days behind our original schedule. These two days were primarily taken up by the anchor overboard test, the winch system test and the modification to the acoustic fish mounting.

Unfortunately at this time the weather was bad with winds 20 to 25 knots northeast and the immediate outlook about the same since the vessel was proceeding eastward with the weather pattern. The Venture was now loaded with approximately 50,000 pounds of hardware and approximately 60,000 pounds of water and fuel, and was floating 1 inch above the d.w.l. at the bow and two inches above the d.w.l. at the stern. Cruising speed was 6-1/2 knots and 36 hours were needed to reach the northern end of Eleuthera.

2.6.3 Launch of Sea Robin IV

The earliest launch for Sea Robin IV was daylight January 13th. During the previous day, the mast and antenna for the buoy were assembled and data transfer established to the

shore station. At 1600 hours January 12th the Venture departed its anchorage, south of Egg Island, Eleuthera for a 12 hour transit to the launch site.

Dawn of January 13th showed winds 15-20 knots with a sea deemed too rough to launch. While waiting on site, urgent business recalled one of the vessel's owners to the mainland and with the weather forecast rather gloomy the Venture returned to its Egg Island anchorage. During Wednesday, January 14th, winds continued 25-30 miles out of the northeast with a prospect of winds veering to the southeast and decreasing during the middle of day.

Launch was rescheduled for daylight January 15th and the Venture again departed its anchorage at 1600 hours on the 14th of January. The dawn of Thursday the 15th of January brought winds 5 to 10 knots out of the east with the residual seas decaying rapidly. The buoy antenna and mast were assembled starting at 0700 hours and the buoy placed over the side at 0800. The 35 foot Rosette, the support boat engaged for this operation, took the buoy in tow using 200 feet of half inch nylon line and the thermistor string was deployed, see Figures 14, 15, and 16.

At the lower end of the thermistor string the cable was clamped and the inclinometer package mechanically and electrically inserted. An intermediate length Kevlar cable was inserted into the mooring at this point by back winding it onto the mooring reel. These components were now deployed over the side using the crane for lifting over the rollers followed by 9000 feet of nylon moor line. The deployed mooring was again clamped off and an additional 1200 feet of line loaded onto the mooring reel and then deployed. (The calculation for this length was made using the on-board PDP 8 computer.) The mooring was now connected to the acoustic release and float assembly which were deployed using the crane with the lower chain assembly tied off, see Figure 17.

The anchor was lifted over the side until supported by a short chain. The AMF 322 transponder release was then attached. The load was taken on the crown line, the short chain removed, and deployment of the anchor proceeded initially with the nylon crown line and continuing to the steel wire rope.

During the deployment of the crown line the wire rope showed a tendency to pull down into the lower reeled layers from which it released with a strong snapping action. This necessitated an extremely slow deployment such that the anchor did not reach its lowest suspended point until approximately 1530 hours.

During the deployment of the anchor the ship had drifted northeast of the designated drop site and it was impossible to maintain any significant net progress without generating excessive side loading on the sheave. With the anchor at its lowest point the ship proceeded slowly towards the drop site. At approximately 1700 hours it was decided that the daylight remaining would permit an anchor drop no later than 1730 hours so as to allow for an inspection of the lower buoy. Accordingly, with the ship maintaining position, Steve Cawthon from the Rosette made a visual inspection dive to examine the lower buoy assembly and remove the lifting cables and tow line. He reported that the fairings were streamed in a single direction and that no strumming was present.

The anchor was dropped by firing the 322 AMF release. A successful implant was established at 015/22/17/17 ZULU. The buoy sank to a free board of about three feet (2 foot lower than calculated) then re-established its design water line for the prevailing winds. Data had been obtained from the buoy from the moment that the antenna was assembled on deck so that environmental data were obtained almost immediately from the instant of launch, see Figure 18.

The Venture proceeded to its Egg Island anchorage to clear customs both for entering and leaving the Bahamas and to prepare Sea Robin III for launch. On Friday, January 16th, it was established that the buoy (SR IV) was not responding to the request for data from the shore station but was transmitting on its own schedule. This was apparently due to off frequency operation of the SSB transceiver in the shore station. Using the single side band transceiver on board the Venture as a reference the shore station transmitter was retuned to match the buoy frequency. Automatic transmission between the shore station and Sea Robin IV occurred immediately.

2.6.4 Launch of Sea Robin III

The Venture was now anchored south of Egg Island. The winds continued to freshen from the NW with occasional gusts of 35-40 knots. The ship was moved in shore to a point 1/4 mile south of Royal Island. At this point clearance with the Bahamian Customs was made and John Gregory of ONR and Mark Switzer of NNPU left to return to the U.S. The shelter from Royal Island was minimal and no work was possible Saturday, 17th.

On Sunday, 18th the foredeck of the ship was prepared for the launch of Sea Robin III. The mooring and anchor were lifted from the hold and placed in position. The Sea Robin III hull was lowered from its position on the upper deck using the life boat davits and floated forward. The crane then lifted and placed it on the foredeck. The buoy was mechanically assembled, the electronic packages inserted and an operational check made. The on-board computer was mated with the system to maintain an operational check until launch.

At this point the weather outlook was not good. The cold front which was causing the high northwest winds was stationary over the area and was not expected to move out until Tuesday night at the earliest with a launch possible Thursday, 22nd. It was decided to make a trip with the Rosette to Nassau for the purpose of picking up some fresh food for the boat and to replace a missing check valve in Sea Robin III. During this visit telephone contact was established with Dr. Sykes (ONR) in order to advise him of the weather delay and the consequent financial impact on the program. Contact with the Venture was maintained via the shore station in Eleuthera. The Rosette returned to the Royal Island anchorage on Wednesday, 21st and the Venture departed for the launch site of Sea Robin III late on that same day.

Dawn on the 22nd brought northeast winds 10-15 knots with residual choppy seas. It was felt however, that with a second front due that evening any further delay would not improve the situation and the launch of Sea Robin III commenced at 0700 hours on Thursday the 22nd of January. The Sea Robin III hull was placed over the side and taken in tow by the Rosette. The Sea Robin III thermistor string was deployed. In spite of the choppy seas the buoy was placed cleanly over the side without impact to the ship's hull at any time. Due to the winds and sea state a reorientation of the original ship's heading was made with the Venture heading northwest and the Rosette towing to the west.

The General Oceanics inclinometer package was inserted without difficulty and the lower nylon mooring deployed. The floats and acoustic release for the mooring were deployed and tied off to the ship.

The anchor was deployed over the side and attached to a short length of heavy chain. The AMF 322 release was then inserted between the anchor and the crown line and lifted by the crane so as to release the chain. At this point the release dropped the anchor which fell abruptly until retained by the chain. The impact partially severed this chain so that the anchor was only held by an open link. The Rosette was warned of the danger and an attempt made to relift the anchor with the crane. The short length of mooring chain formerly held by the acoustic release was attached to the crane hook and used to lift the anchor. However, it was not possible to remove all the chain from the anchor because of distortion of the shackle at the anchor. It should be pointed out that this attachment point was in the vicinity of the waterline of the vessel so that the anchor was below the hull to prevent damage to the hull from swinging. The 322 release was inserted and the procedure continued with the lowering of the anchor. The broken chain was allowed to fall down to the level of the anchor and did not appear to interfere with the operation.

The anchor was lowered to its final depth. While this was taking place the Rosette proceeded to a point southeast of the Venture. With the buoy in tow the Venture maintained headway into the southeast flowing Eleuthera Counter-Current. We continued over the canyon (Figure 20) and with the anchor now stationary at its final depth, proceeded up the shallow slope to the anchor site. At the expected location the anchor touched bottom and a dynamometer which had been installed on deck during the lowering process, indicated an abrupt drop in tension. To confirm this the ship was allowed to drift back to lift the anchor, and then replace the anchor onto the ocean floor. (See Figure 19.)

At this point additional crown line was released and the ship allowed to move slowly forward towards the northwest. Sea Robin III was now sitting at her expected waterline and the launch appeared good. The Rosette was released from the buoy, the AMF 322 release was fired to separate the crown line from the anchor and the Venture pulled forward to clear the crown line from the mooring. Approximately 3 to 4 minutes later Sea Robin III abruptly sank to a depth of at least 200 feet. (The 200 foot tow line was still attached to the buoy and this line, floating at its upper end, was also pulled under.) The Sea Robin III acoustic

release was actuated. However confirmation of this release was not positive due to the high background noise level.

The Venture proceeded at the same pace with an approximate net headway of 1/2 knot while the crown line was retrieved as rapidly as possible. The Rosette continued to search for any indication of debris. At this point it was observed on the bathymetry that the lower crown line was lifting an object. With the hope that we were possibly raising the sunken mooring the operation was continued. However, when this object reached a depth of 3400 feet the tension in the crown line rose abruptly causing the crown line to jump the sheave along with a sudden tremor to the ship. The tension immediately dropped and the image disappeared from the bathymetry. Retrieval of the crown line continued and the 322 release satisfactorily recovered. The release had obviously suffered extreme downward pressure on the housing causing it to slide down the tension shaft until jammed against the release lever.

The Venture continued a down current search both visually and acoustically and returned up current later. No indications were found. The Rosette proceeded towards Sea Robin IV for the purpose of checking the navigation light. On approaching the Sea Robin IV site the navigation light was spotted. In view of continued worsening bad weather the Venture returned to the Royal Island anchorage and then to Miami for off-loading.

2.6.5 Demobilization

The Venture arrived in Miami on the evening of Saturday the 24th and cleared Customs and Immigration. On Sunday 25th, electronics gear was off-loaded and the GE van departed for Philadelphia. The remaining hardware was off-loaded and the Venture released as of 1700 hours, 26th of January. The Rosette was released as of 1700 hours on the 25th of January.

2.6.6 Summary

The Sea Robin IV buoy implant had proceeded exactly as planned and data had been received from before the implant up to about mid-March 1976. One of the 18 thermistors behaved irratically after 6 days the other 17 remained accurate until transmission ceased.

With regard to Sea Robin III, using all of the known information, it has been concluded that the anchor did not spin freely during its descent to the ocean floor. It is possible that the swivel was damaged by the impact loading when the anchor was dropped. Consequently,

the mooring line and the crown line were likely twisted together when the anchor was released and the 322 transponder-release slid upwards until it hooked the nylon in the lower mooring. With the ship proceeding upstream the buoy was pulled below its crush depth. At this point the crown line continued to lift the mooring until the nylon was severed, probably by the corners on the release.

2.7 Recovery of Sea Robin IV

The Sea Robin IV buoy was placed on automatic operation on 16 January with the Eleuthera-Valley Forge transmission effective January 24, 1976.

On February 13 data transmission from the buoy ceased at 1540 Z, but recommenced at 2033 Z. Analysis of AGC data and observations by the GE monitor confirmed the operation of a high powered transmitter at Eleuthera during these hours.

Starting on March 8 from 0000 Z to 1200 Z, data obtained from the buoy became intermittent due to the co-existence of a near continuous outside data transmission on the buoy frequency. This continued daily. Only very occasional buoy transmissions were received. An effort was made by U.S. Navy personnel at Eleuthera to determine the source of this interference. Only the fact that it originated offshore was determined.

On March 17 the buoy ceased transmitting. This was noted simultaneously at Valley Forge and Eleuthera, but could not be confirmed until after the background interference, noted above, had ceased.

The buoy was confirmed as not being on station. Subsequently, ship reports indicated that it was adrift and that the mooring had been severed close to the buoy. Following the initial report, the buoy was not seen even though several light aircraft searches were made. One of the difficulties lay in the unknown amount of windage on the hull. If large, the buoy would have been carried westward sufficiently to enter the Eleuthera countercurrent and hence be carried southeastward. However if the windage was not large the buoy would carry northwestward.

The R.V. Venture left Miami on March 26th to attempt to retrieve the Sea Robin IV mooring and buoy. While searching for the mooring the buoy was sighted and recovery made March 29th. The RPG was transferred to the Institute for Acoustic Research in Miami and the buoy placed in storage at the NOAA yard on Dodge Island.

By observation it was determined that the fairlead had failed where the wire structure joined the flanged steel housing (see Appendix Ref. A11). The buoy antenna had failed immediately below the radar reflector. The steel housing and upper cable section were taken to the manufacturer, Preformed Line Products Company (PLP), Cleveland, Ohio for examination. Subsequently, these items were delivered to NRL Code 6310, Micromechanical Criteria for an in-depth analysis.

At GE a review was made for evidence of overloading and to determine the sequence of failure. On February 23 (the 54th day), two individual mooring line tension values had been recorded at almost twice the average tension. Winds had been 15 knots, N.E. with only a moderate sea. Tire marks on the buoy indicated that a ship had tied up to the buoy. The pressure of the tire imprint was sufficient to leave the tire size and rating legible on the buoy and to determine that it was probably U.S. manufactured. Calculations show that a moderate sized vessel, 80-150 feet long, if tied to the buoy, would produce sufficient side load to increase the tension to the 3800 pound value recorded. However, the tire marks indicate that the buoy was essentially upright during this event and it was concluded that no evidence of undue bending of the fairlead at that time exists.

Analysis of the temperature data from the data tapes indicates that the thermistor conductors failed over a 24 hour period, March 6 and 7, 1976. The failure pattern indicates that the conductors were broken (open circuit) and then occasionally remade contact for a period of time.

A consistent story was generated from the analysis of NRL and a review of the buoy data. Prior to March 6 over an undetermined period of time, the outer rods in the fairlead failed due to a combination of fretting fatigue and corrosion.

During this period winds were 25-40 knots, N.E., and the mooring line tensions reached 2800 pounds. The buoy motion was not measured, but pitch angles of $\pm 6^{\circ}$ would be expected and this would be sufficient for the unanchored outer rods to move within their housing.

The continued motion of the buoy together with the reduced strength due to the loss of the outer rods resulted in the loss of the inner rods, leaving sharp edges adjacent to the thermistor string. Approximately 24 hours were needed for the sharp rod ends to cut through

the conductors. Only the center strength member remained. This was U.S. Steel "Tiger" brand wire rope, 3/8" diameter, and took 12 days before it was finally worn through by the sharp edges of the broken outer structure.

Upon failure, the buoy lay near horizontal in the water. Wave action against the radar reflector probably caused this to break. It is highly likely that the buoy did continue to transmit for a period of time following buoy mooring failure. (During the launch continued 100% data transmittal occurred while the buoy was horizontal.) However, the mooring failure occurred during a period of strong RF interference and any chance of maintaining contact was lost.

It should be noted that all electronics worked 100% correctly on recovery. The buoy was continuing to attempt to transmit its data regularly. Note further, that the inclinometer and Loran data did latch correctly in the laboratory after recovery. However, if RF noise, similar to that emitted by the RPG is induced, then data latching can occur prematurely.

The following conclusions are reached from the above discussion and by separate observations:

(1) The fairlead, the intent of which was to prevent fatigue failure of the thermistor string, itself failed as a result of the lack of anchoring of the outer rods. The mooring failed as a result of the fairlead failure.

(2) At some time during the experiment a ship tied to the buoy. No indication that this indeed caused overloading, however, estimates show that this ship could have overloaded the fairlead.

(3) The RPG worked excellently as a power source. The RF noise from its DC/DC converters is, however, a source of electronic troubles.

(4) Even though a U.S. Navy assigned frequency was used, strong RF interference was observed. This negated most of the safety precautions needed by the presence of the RPG.

(5) All recovered buoy hardware and electronics were in excellent condition with no corrosion apparent after 60 days at sea.

(6) Excellent temperature data were obtained for a significant time period.

2.8 Subsequent Events

During the buoy operation data were processed and temperatures computed. Subsequently, the old data tapes were collected and the data processed as a single batch. This data processing is described in more detail later.

Sea Robin IV was placed in storage in Miami, Florida. The electronics were found to be in perfect operational condition. Both hull and electronics are in directly usable condition.

3.0 RESULTS

The data from Sea Robin IV and other data from the program are presented here. Processing of the data will be described and the procedure for connection of the sensor depths discussed. Because of the relationship of the depth correction to the nylon characteristics the results of the nylon testing program will also be discussed. The temperature data are presented and certain fixtures are described. In addition, certain thoughts on the nature of the Eleuthera counter-current will be given.

3.1 Nylon Rope Characteristics

Analysis of the compliant taut moor requires a knowledge of the elasticity of the nylon. At the time of initiation of the design (1971) the plaited nylon rope was relatively new on the market and accurate information was not available.[7] Hence a testing program was conducted at GE-OSL to determine the important characteristics. Appendix A includes a description of this program and the apparatus used.

Certain features of the results are discussed here. To eliminate uncertainties in length the rope is tensioned for one hour at 5% of the breaking strength and, for that sample of rope an elongation of 13% assumed at the load and time. This defines a zero tension length (at one hour). Using this reference, load elongation curves were obtained as shown in Figure 21. Tests were made wet and dry and at widely varying temperatures. The data correlated well.

The elongation of the rope continues with time at constant load (21% of break). Figure 22 shows the continued elongation with time. Approximately 2% additional elongation occurred over 1 year (from one hour).

These characteristics were incorporated into the mooring analyses and such analyses are now made for both 1 hour and 1 year mooring durations. This information has also been incorporated into the analysis of sensor depths.

3.2 Correction for Sensor Depth Variations

Data from the thermistor string is measured at specific sensor locations; i.e., specific distances along the string. The compliant taut moor uses the elasticity of the nylon to allow the mooring to become inclined and hence balance the drag. The sensors are not at the nominal depths but at some depth above the nominal values. These depths must be determined.

It is apparent that one prime measure of the depth excursion is the tension in the mooring. This tension, measured at the buoy, represents (to first order) the wet weight of the string plus the tension at the thermistor string - nylon interface. The nylon tension will be a sum of the tension at the interface plus an increment from elongation of the nylon due to changes in the mooring geometry from drag on the mooring. The first term, the baseline tension, represents the elongation of the nylon due to the scope* being less than unity. Because of the nature of the nylon this tension is not constant but decreases with time.

The elongation of the nylon would be expected to be related to the depth of the thermistor string-nylon junction. Hence, it should be possible to relate the sensor depth excursions to the mooring tension.

To test this concept, a numerical exercise was performed using a computer. Given a current profile, the surface wind was assumed and the mooring geometry computed. For each thermistor the depth correction

$$\Delta Z_n = Z_n - S_n$$

was computed. Here Z_n is the depth and S_n the nominal depth for the thermistor. This was repeated for 15 different combinations of current profile and winds. It included planar and skewed currents along with complete variations in wind direction. Maximum currents were 1.8 knots and maximum wind speeds were 50 knots.

The resulting values for ΔZ_n were correlated with tension and nominal depth. The correlation formed was

$$\Delta Z_n \propto (AT-BT)^{K1} \; S_N^{\;K2}$$

where AT is the line tension averaged over about 2 hours and BT is the baseline tension. The correlation is shown in Figure 23. The data correlates for all thermistors. A single relationship for ΔZ can be made with resulting error ϵ_n.

The maximum excursion, corresponding to the highest currents and winds and the deepest thermistor (S = 1490m) gives $\Delta Z \sim 40$ m with $\epsilon \sim 2$ m. Elsewhere the errors are generally bounded by $\epsilon = 2$m.

*See Page 4.

If the winds were assumed less than 20 knots and the currents less than 1 knot, the variation is reduced considerably. Worst case ΔZ is now 22m and $\epsilon \sim 1$m throughout.

Examination of the data shows that winds were below 20 knots for all but brief periods on days 46 and 47. Hence the uncertainty of the sensor depths, when corrected, was assumed to be of order 1m.

3.3 Processing of Sea Robin IV Data

The data from Sea Robin IV was transmitted in raw binary form. The data layout is shown in Table 2. The data includes temperature data and other information to monitor the system operation as well as to assist in the data reduction. The shore station added time information and meteorological data, and stored the data on DEC tape. These tapes formed the basis for the data processing. Refer to Appendix B.

Figure 24 shows this stage and subsequent stages in the data processing sequence. The DEC tapes were mailed to Valley Forge and converted to temperature, meteorological factors, etc., using a DEC PDP 8/e. Programming was in FOCAL, a DEC interpolative language which is simple and easy to use although slow. Linear conversion of the binary voltages was straightforward representing inversion of the A/D conversion on board Sea Robin IV.

Measured thermistor voltages were then converted to resistance values by

$$R_{T_i}(K\Omega) = \frac{V_{T_i} + G_i(1-0.4\,E_o)}{A_i - V_{T_i}/B_i}$$

Where A_i, B_i, G_i are given in Table 3, and E_o is the return current in the circuit. It should be noted that E_o depends on all thermistor values and is negligible only if all thermistors are operating correctly. E_o was monitored directly but could be computed if necessary.

Thermistor temperatures were then derived by:

$$1/T_i\,(^oC) = \sum_{j=1}^{3} C_{i,j}\,(\mathrm{Ln}\ R_i/10)^{j-1}$$

where $C_{i,j}$ are given in Table 4.

The coefficients A_i, B_i, G_i and $C_{i,j}$ were derived from calibration of the thermistor string. Temperatures were accurate to 0.03°C over the range.

$$0 < T < 30^{o}C$$

The line tension was derived from either word 30 or 31 and

$$T_N(\text{lbs.}) = 120 + 1633.33V$$

A 9-point moving average of the instantaneous tension was computed:

$$AT = \frac{1}{9} \sum_{K=1}^{9} T_{N_{(K)}}$$

Finally, a "sea state parameter" was calculated:

$$SS = \frac{1}{9} \sqrt{\sum_{K=1}^{9} (T_{N_K} - AT)^2}$$

The resulting processed data was stored on magnetic tape. A separate programming step transferred this data to a Honeywell 6060 computer.

This transfer was accomplished using a 300-band telephone link. The DEC tapes were read on the PDP 8; calculations were made using FOCAL; and, output was sent to the terminal connected to the H6060. Using the TSS EDIT subsystem, a data file was constructed in BUILD mode. In order to avoid loss of data while building the file, transfer is interrupted every 20 blocks and a LISTL command causes the current buffer to be written, then BUILD mode is resumed. This procedure is accomplished under program control, allowing unattended operation of the transfer.

As an alternative, a 7-track tape of data was generated on the PDP 8. However, the above data transfer was found quite satisfactory and the 7-track tapes were not used.

At this point certain editing of the data was accomplished which was necessary to remove data with occasional bit errors from the telemetry. Editing was performed by scanning 5-day sequences of temperatures on a Tektronix 4012 display, allowing identification of spurious excursions of data. This procedure resulted in deletion of erroneous data prior to final graph preparation. Approximately 20 blocks of data were deleted out of a total of about 5000 blocks.

Since the thermistor string was not vertical it was necessary to correct the data so that temperatures at constant depth could be derived. The mooring tension was the parameter used.

A baseline tension was computed:

$$BT = 1500. \left[1 - 0.032 \, Ln(H - H_o) \right]$$

where H is the sample time in hours from midnight, January 1, 1976 and H_o is the launch hour (374) measured from the same time. This baseline tension made allowance of the change of nylon line characterization with time. A function

$$f(T_N) = 31 \left[\frac{AT - BT}{1000} \right]^{1.29}$$

was computed using the 9-point moving average of the instantaneous tension, AT.

Next, the corrected depth for a given thermistor is derived by:

$$Z_{A_i} = Z_{o_i} - f(T_N) H_{Z_i}$$

and the temperature corrected to the nominal depth is

$$T_{C_i} = T_{M_i} - f(T_N) G_{Z_i}$$

where Z_{o_i} is the nominal depth in meters and T_{M_i} is the measured temperature. H_{Z_i} and G_{Z_i} are as given in Table 5.

The sound speed was computed from Wilson's formula using a T/S relationship derived for the western Antilles current from data by Woods Hole Oceanographic Institute.[8]

Finally, we may locate an isotherm of T_K by

$$Z_K = Z_{o_K} + \frac{T_K - T_{C_K}}{G_{Z_K}} \cdot H_{Z_K}$$

where Z_{o_K} is the nominal depth of that thermistor near T_K, in meters, T_{C_K} is the corrected temperature of that thermistor in ^oC, and G_{Z_K} and H_{Z_K} are as given in Table 5.

A final step in the data reduction process is the plotting of the data.

Plotting was accomplished using the CalComp 936 digital plotter, from the edited data tape. The output tapes were input to the GIPS post-processor program with a scale factor value of 1.0 or 0.3, to allow plotting on either 33 inch wide paper or 11 inch wide paper, respectively.

3.4 Discussion of Sea Robin IV Data

Processed temperatures are shown in Figure 25. Each thermistor temperature history was plotted for the period day 16 to day 54, 1976 with the days terminated at 2400Z. The data exhibits a full spectrum of fluctuations and is extremely self consistent. It should be noted at the outset that each thermistor temperature was computed directly from the calibration constants obtained in the laboratory without adjustment of individual levels.

Using the correction procedure discussed earlier, the data was replotted in Figure 26 with the temperature corrected to the constant nominal depths. This correction was not very large amounting to 0.2 to 0.3°C at most. In many cases the correction was only a few hundredths of a degree C.

Missing from this figure is the thermistor at 100m and part of the temperature history at 1005m. The records were considered suspect and it was felt better to eliminate any suspect data rather than try to correct it.

Figure 27 shows isothermal records derived from the thermistor data. Isotherms were computed in two ways. The first was to use interpolation for each temperature profile. In this case the isothermal fluctuation represents averaging of the fluctuation of a number of thermistor records. The second way was to use individual thermistor records but convert to isothermal depths using the load gradients computed from adjacent thermistors. In general, fourth order polynominal curve fits were made for interpolation and gradient determination.

It was decided to use the second approach as having somewhat more physical significance. However, it should be noted that a comparison between the two approaches showed very little in numerical differences.

The sound speed variations are shown in Figure 28. Each thermistor has a baseline which is chosen to allow representation of the fluctuations as a common scale.

Finally, other buoy data are shown in Figure 29; namely, wind speed and direction, averaged line tension and the sea state parameter derived from mooring line tension fluctuation.

Detailed analysis of this data is scheduled to be performed in the future. Some comments on the phenomena can be made at this time, however. Temperature fluctuations over a wide range of time scales can be clearly seen. The smallest scale represented is less than 1 hour and this is superimposed over all thermistors for the duration, with the exception of near surface measurement ($Z = 7$ meters). Such small scale fluctuations are generally 0.1 to 0.2°C in amplitude but decrease at the low levels. Isothermally these represent fluctuations of over 10m in amplitude and this appears constant with depth.

Note also that these fluctuations should not be due to electronic noise. In addition to the thermistor amplifiers on board Sea Robin IV, two identical amplifiers with constant voltage inputs also contributed data. Examination of the "noise" from these channels shows that the total system noise through data processing is about 0.02°C and that the final thermistor assembly had measured time constants of about 2 minutes. This reduced fluctuations of the temperatures due to vertical oscillations of the mooring from wave action. Thus the noise equivalence that remains is also of order 0.01 to 0.02°C.

The second scale of the fluctuation which is readily apparent is semi-diurnal. Peak fluctuations occur in the permanent thermocline. The physical amplitude does not decrease, however, and amplitudes from 20 to 50m can be seen throughout the water column.

Three small scale eddies are apparent during the 40 day span. They appear to be about 3 days in period and some 1-2°C in amplitude (or 50-100m). The interval between adjacent eddies was about 12-13 days.

The vertical correlation is quite apparent. The first appears to occur from the surface to about 200m. The second is from 150 to 850m and the third again is near the surface, $Z < 250$m. If these eddies were convecting with the Antilles current, then the horizontal scale would be of 100 km. This is of the same order (radius) as the distance from the Eleuthera escarpment. A possible source of small scale eddies is the island of San Salvador which represents a column in the Antilles current and could shed eddies with frequencies of about 10 days. A longer sampling time at that site could allow for examination of the repeatibility of this phenomenon.

In the last 10 days of the sample period a decline in temperature is seen between 250 and 900 meters. This could be a larger eddy of some 20 days duration. Maximum temperature decline was 2-1/2^{o}C at 650 meters and vertical displacements were ~ 100 meters. Again the sampling period was too short to examine more of this phenomenon.

The data represented here are now stored on magnetic tape suitable for computer processing. In the future the energy spectra for these fluctuations will be examined. In addition, vertical coherence scales will be investigated by examining cross correlation spectra.

The other environmental data shown in Figure 29 should receive brief comment. The nature of winter weather in the area is that of a continuous sequence of fronts. Winds are generally north-northeasterly and seas are rarely calm. Measured winds were in many cases 15-20 knots with higher gusts. While these are not severe enough to modify deep ocean data they did make ship-buoy operations more hazardous.

3.5 Discussion of Observed Currents

The survey voyage described earlier did result in some crude measurement of the currents. The currents were generally parallel to the Eleuthera escarpment with offshore currents being negligibly small. Figure 30 shows the currents at the surface derived from the ship tracks. The northwesterly flowing Antilles current would appear to have had its western boundary about 18-19 n. miles offshore at this place and time. From 4-10 n. miles there existed a strong southeasterly current. Offshore and between this and the Antilles current were essentially slack intermediary zones.

This southeasterly flow has been called the Eleuthera counter-current. Other measurements and observations, during both the launches (Sea Robin III as well) have supported the concept that this current is a permanent feature and not transient, and that the flow is deep and not purely a surface phenomenon.

The origin of the Eleuthera counter-current is not known. However there is a distinct possibility that it is found in the southerly flowing current that was discovered between the Antilles current and the Gulfstream north of Grand Bahama Island which could then follow the eastern edge of the escarpment that fringes the Bahamas chain. If this were so then several features could be foreseen. First a temperature difference could be expected with the Eleuthera counter-current somewhat lower than the Antilles current. This was indeed

observed in the XBT traces. Secondly, since this counter-current must cross the entrance to the Northeast Providence channel which is the major entry for tidal induced flows into the tongue of the ocean then it would be expected that the Eleuthera counter-current would be modulated so that its width varied semi-diurnally. No observations of the boundaries were attempted. However, if it existed, this modulation would certainly affect the geometry of the acoustic rays and hence the received signals.

4.0 CONCLUSIONS AND RECOMMENDATIONS

While the program is not complete certain conclusions can be drawn. The detailed data analysis can be expected to give some important results on the nature and magnitude of thermal fluctuations. A preliminary summary on the scales of the fluctuations has been possible.

An additional environmental factor, the Eleuthera counter-current, has been identified and may be acoustically significant. Since little is known about it at the moment, additional studies on its effect would appear to be valuable.

The compliant taut moor and modified spar buoy combination would appear to be a viable approach for the sensor array operation. This technique is not particularly easy, nevertheless the skills for its use have been developed and proven, and problems with the strain relief component are solvable. Most of the hardware worked perfectly.

The feasibility of employing two Sea Robin Buoy/Thermistor String arrays to define the environmental nature of the initial acoustic path remains sound. Together with subsurface current data the second facility would provide needed horizontal scaling verification.

References

1. J.C. Steinberg, J.G. Clark, H.A. DeFerrari, M. Kronengold, and K. Yacoub, "Fixed-System Studies of Underwater-Acoustic Propagation," J. Acoust. Soc. Am. 52, 1521-1535 (1972).

2. J.G. Clark, N.L. Weinberg, and M.J. Jacobson, "Refracted, Bottom-Reflected Ray Propagation in a Channel with Time-Dependent Linear Stratification," J. Acoust. Soc. Am. 53, 802-818 (1973).

3. J.G. Clark and M. Kronengold, "Long-period fluctuations of CW signals in deep and shallow water," J. Acoust. Soc. Am. 56, 1071-1083 (1974).

4. Maloney, W.E., "A Study of the Antilles Current Using Moored Current Meter Arrays," Naval Oceanographic Office, Washington, D.C., 8/67.

5. Pratt, J., Gray, E., Schuyler, F., "Analysis and Computer Program Describing the Dynamic Planar Motion of a Surface Buoy," GESSL PIR 2A20-000-58, 8/19/71.

6. Pavlak, A., Softley, E.J., Hoppmann, R.F., "A Thermistor String For Use In The Deep Ocean." GE TIS 71SD246, 8/18/71.

7. Columbian Rope Company, Auburn, N.Y., Product Bulletin #R-1, 10/1/69.

8. F.C. Fuglister, "Atlantic Ocean Atlas." Woods Hole Oceanographic Institute.

TABLE 1 CABLE OPTIONS

	% Load		Comments
	Center Strength	External Armor	
1.	100	0	Dimensional stability maintained Limited fish-bite protection
2.	0	100	Armor must be cut to insert thermistors Conductor folding necessary
3.	50	50	Armor must be cut Dimensional matching at cut critical
4.	80	20	As 1 but some fish-bite protection
5.	20	80	Armor must be cut Good fish-bite protection Severe dimensional matching problem

TABLE 2

RAW DATA LAYOUT

Word #	Datum	Word #	Datum
0	"SYNCH" = 3465_8	24	Inclinometer channel A
1	5V reference = 3777_8	25	Inclinometer channel B
2	T_1 (Thermistor String Voltages)	26	Nav. Light Battery ÷ 10
3	T_2 (Thermistor String Voltages)	27	1.4V ref.
4	T_3 (Thermistor String Voltages)	28	Thermistor return current
5	T_4 (Thermistor String Voltages)	29	2.8V (28V battery ÷ 10)
6	T_5 (Thermistor String Voltages)	30	Tensiometer, high range (0-7500)
7	T_6 (Thermistor String Voltages)	31	Tensiometer, low range (0-750)
8	T_7 (Thermistor String Voltages)	32	0 (overlayed by HR*)
9	T_8 (Thermistor String Voltages)	33	SV (overlayed by MIN/SEC*)
10	T_9 (Thermistor String Voltages)	34	RPG voltage ÷ 10
11	T_{10} (Thermistor String Voltages)	35	2.4V ref.
12	T_{11} (Thermistor String Voltages)	36	$\|u\|$ wind velocity
13	T_{12} (Thermistor String Voltages)	37	$\vec{u}$ wind direction
14	T_{13} (Thermistor String Voltages)	38	P_a atmospheric pressure
15	T_{14} (Thermistor String Voltages)	39	LORAN channel 1
16	T_{15} (Thermistor String Voltages)	40	LORAN channel 2
17	T_{16} (Thermistor String Voltages)	41	Buoy status: bit 0 Unused
18	T_{17} (Thermistor String Voltages)	42	Buoy status: bit 1 0 = LORAN A, 1 = LORAN B
19	T_{18} (Thermistor String Voltages)	43	Buoy status: bit 2 1
20	T_{19} (buoy internal)	44	Buoy status: bit 3 H_2O Leak 1
21	T_{20} (buoy external)	45	Buoy status: bit 4 0
22	Drift, amplifier 20	46	Buoy status: bit 5 H_2O Leak 2
23	Drift, amplifier 19	47	Buoy status: bit 6 0
			bit 7 Unused
			bit 8 1
			bits 9-11 Unused

* Time is encoded as YR, DAY, HR, MIN/SEC into 4 words

1. YR ($76_{10} = 114_8$)
2. DAY 0 - 366
3. HR 0 - 23
4. MIN/SEC bits 0 - 5 = MIN, bits 6 - 11 = SEC

TABLE 3

COEFFICIENTS TO DERIVE R_T FROM E_T:

$$R_T = \frac{E_T - G_i\,(1 - .4\,E_o)}{A_i - \frac{E_T}{B_i}}$$

Thermistor No.	A_i	B_i	G_i
1	0.1502	85.50	-0.08
2	0.1450	96.75	+0.08
3	0.1483	89.40	-0.08
4	0.1469	97.43	+0.08
5	0.1485	89.16	-0.08
6	0.14665	97.46	+0.08
7	0.1478	89.82	-0.08
8	0.1461	97.30	+0.08
9	0.1490	89.47	-0.08
10	0.1474	96.80	+0.08
11	0.1486	88.96	-0.08
12	0.1470	96.90	+0.08
13	0.1485	89.16	-0.08
14	0.1460	97.10	+0.08
15	0.1490	89.24	-0.08
16	0.1455	96.80	+0.08
17	0.14865	89.40	-0.08
18	0.14715	97.02	+0.08
Internal 19	0.1465	97.00	-
Surface 20	0.1485	89.16	-

TABLE 4

$$1/T_i = \sum_{1=j}^{3} C_{ij} \left[\text{Ln } R_i/10.\right]^{j-1}$$

Thermistor No.	$C_{i,1}x10^2$	$C_{i,2}x10^3$	$C_{i,3}x10^4$
1	0.327374	0.236341	+0.381546
2	0.322991	0.314108	-0.351063
3	0.326888	0.289618	-0.201969
4	0.322677	0.315390	-0.330132
5	0.322724	0.309967	-0.232622
6	0.321548	0.306715	-0.161324
7	0.324351	0.276791	-0.0521851
8	0.305901	0.666451	-1.84373
9	0.326473	0.252797	+0.0682391
10	0.325296	0.268671	-0.0364263
11	0.322319	0.320863	-0.266759
12	0.320281	0.307068	-0.204762
13	0.322263	0.286721	-0.164678
14	0.323553	0.432433	-0.942984
15	0.325287	0.318621	-0.270613
16	0.326407	0.269543	-0.041056
17	0.322466	0.315166	-0.229121
18	0.327590	0.293214	-0.104114
19	0.325000	0.300000	-
20	0.325000	0.300000	-

TABLE 5

Thermistor No.	Z (Meters)	H_Z	G_Z
1	150	0.0651	0.0022
2	250	0.1359	0.0014
3	350	0.2205	0.0027
4	450	0.3167	0.0059
5	550	0.4228	0.0091
6	650	0.5378	0.0119
7	750	0.6608	0.0132
8	850	0.7914	0.0126
9	950	0.9288	0.0112
10	1050	1.0728	0.0082
11	1150	1.2229	0.0070
12	1250	1.3790	0.0065
13	100	0.0363	0.0013
14	200	0.0985	0.0017
15	1005	1.0072	0.0093
16	1100	1.1471	0.0074
17	1200	1.3002	0.0065
18	1490	1.7758	0.0065
19	7	0.0000	0.0000

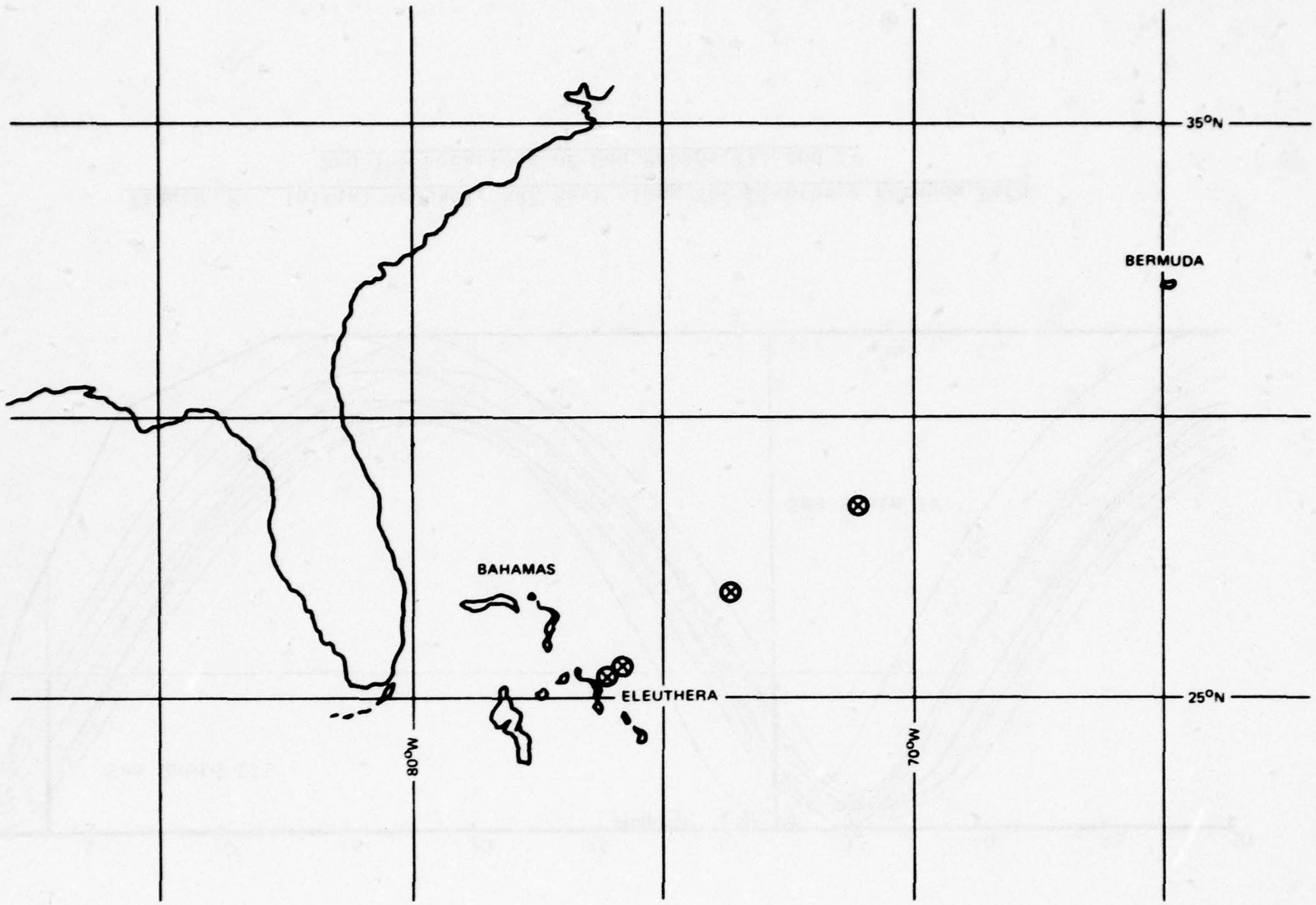


Figure 1. Multiple Sea Robin Buoy/Thermistor String Facilities As Originally Conceived.

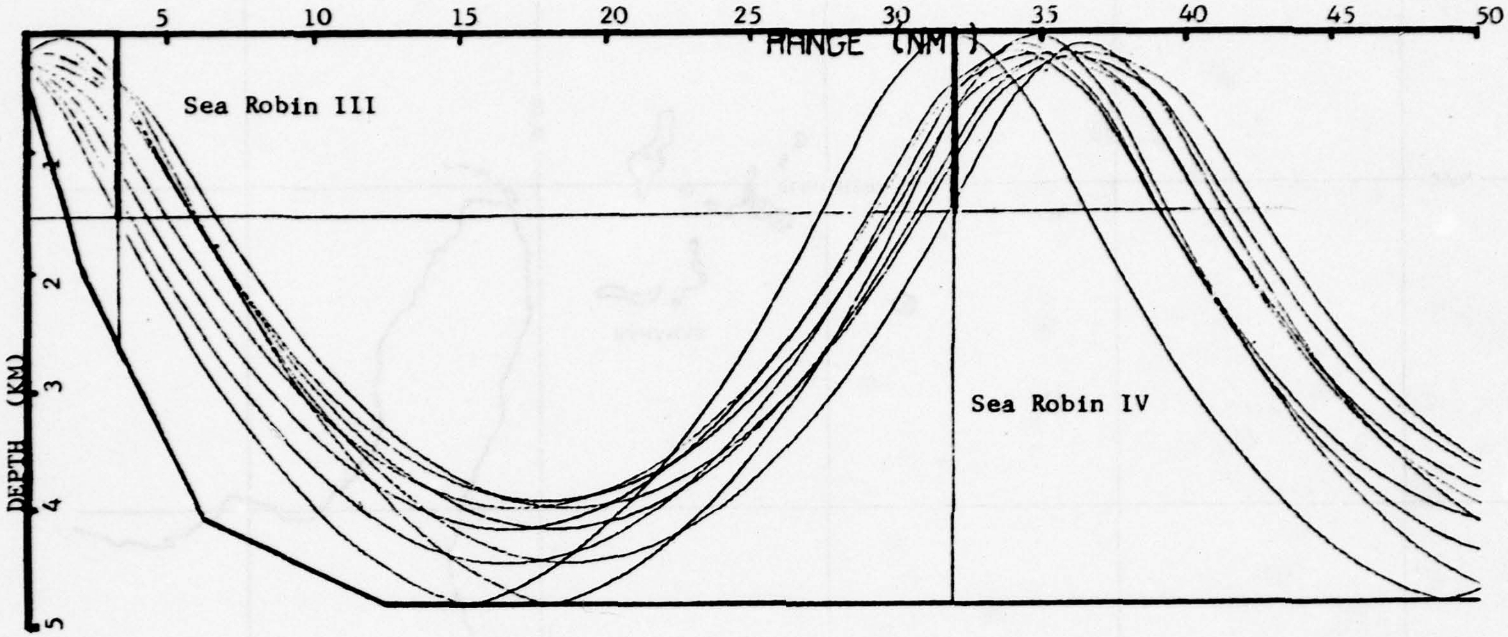


Figure 2. Initial Acoustic RRR Rays Along The Eleuthera Bermuda Path And The Locations Of Sea Robins III and IV

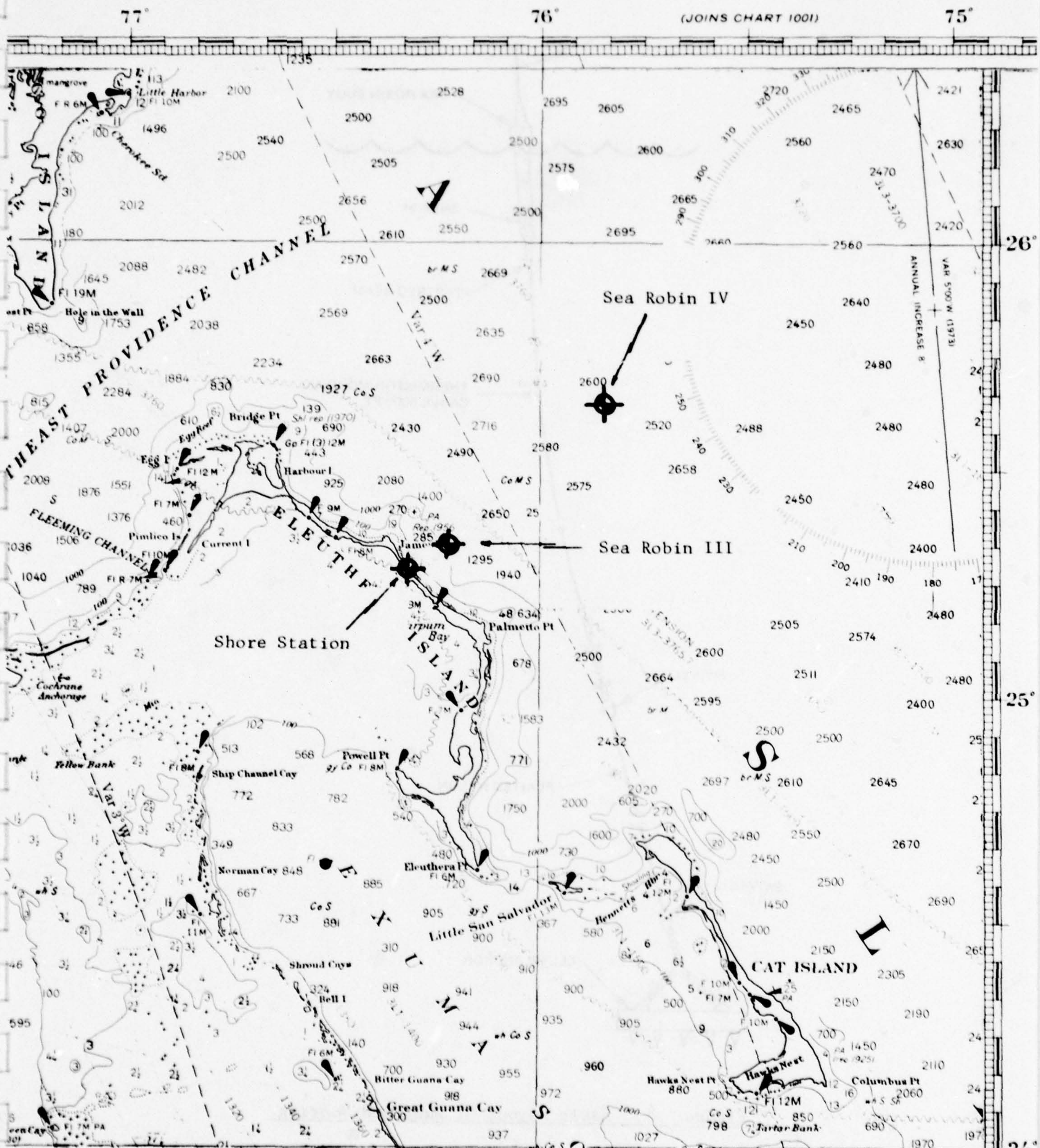


Figure 3. Location Of Sea Robins III and IV.

41

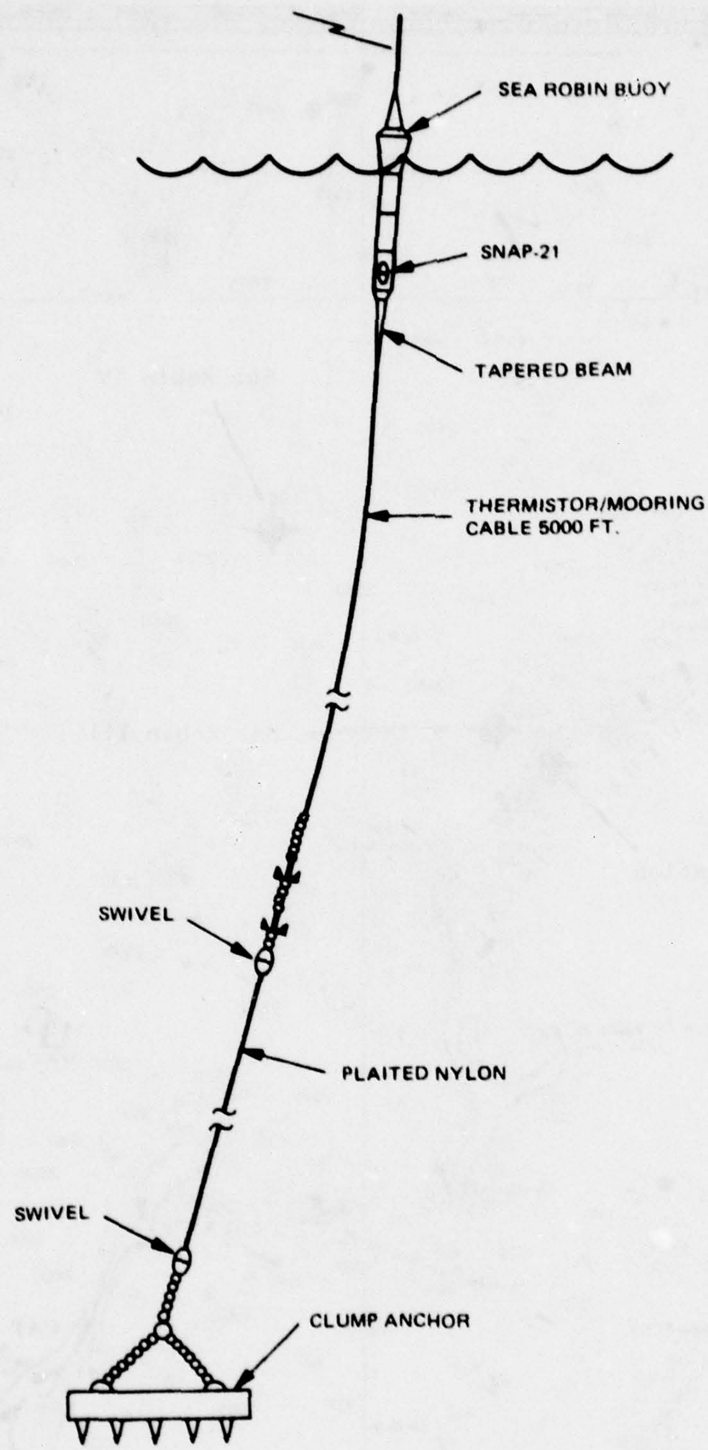


Figure 4 Basic Layout Of Buoy And Mooring.

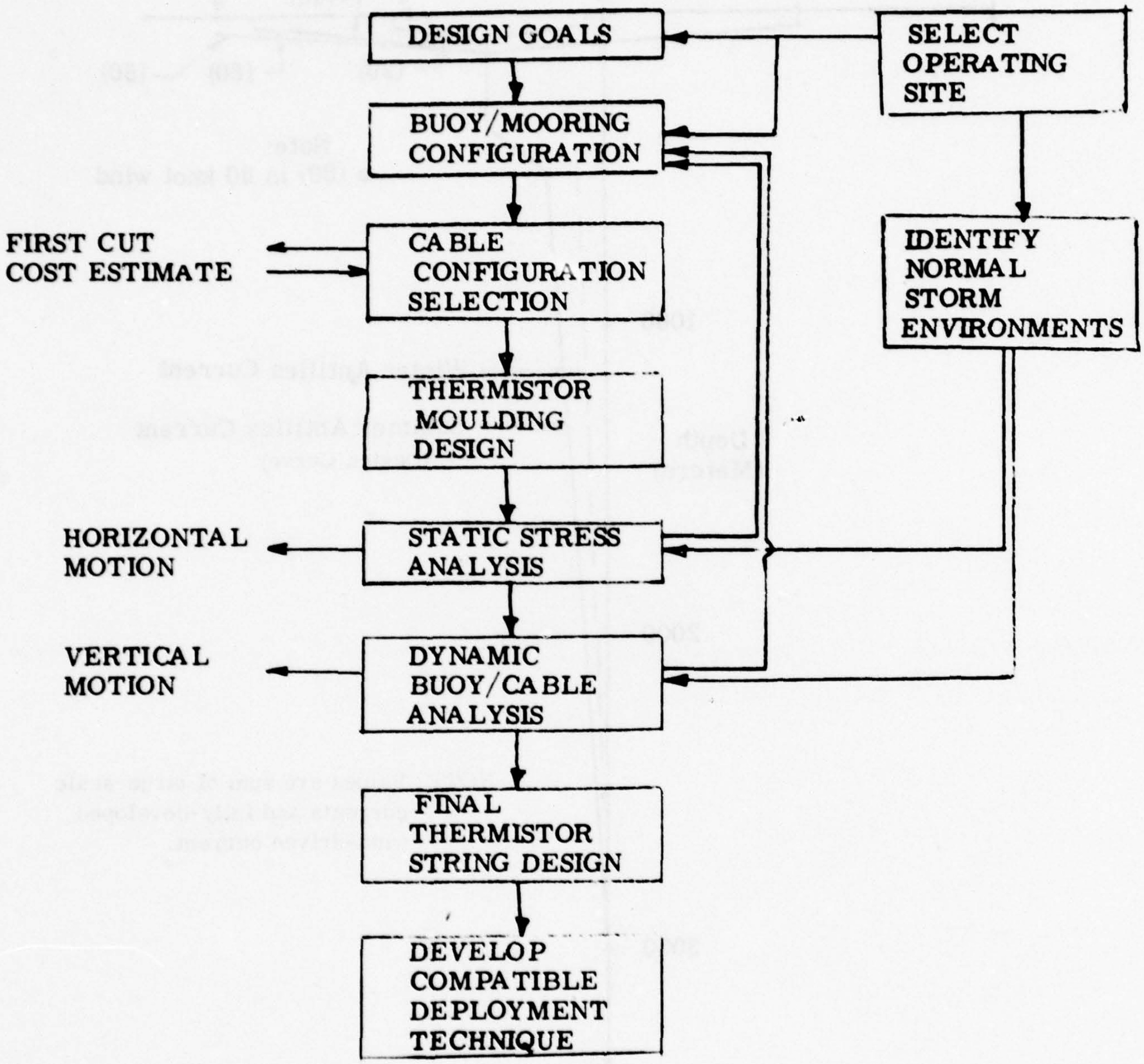


Figure 5 Design Logic For Thermistor String Mooring.

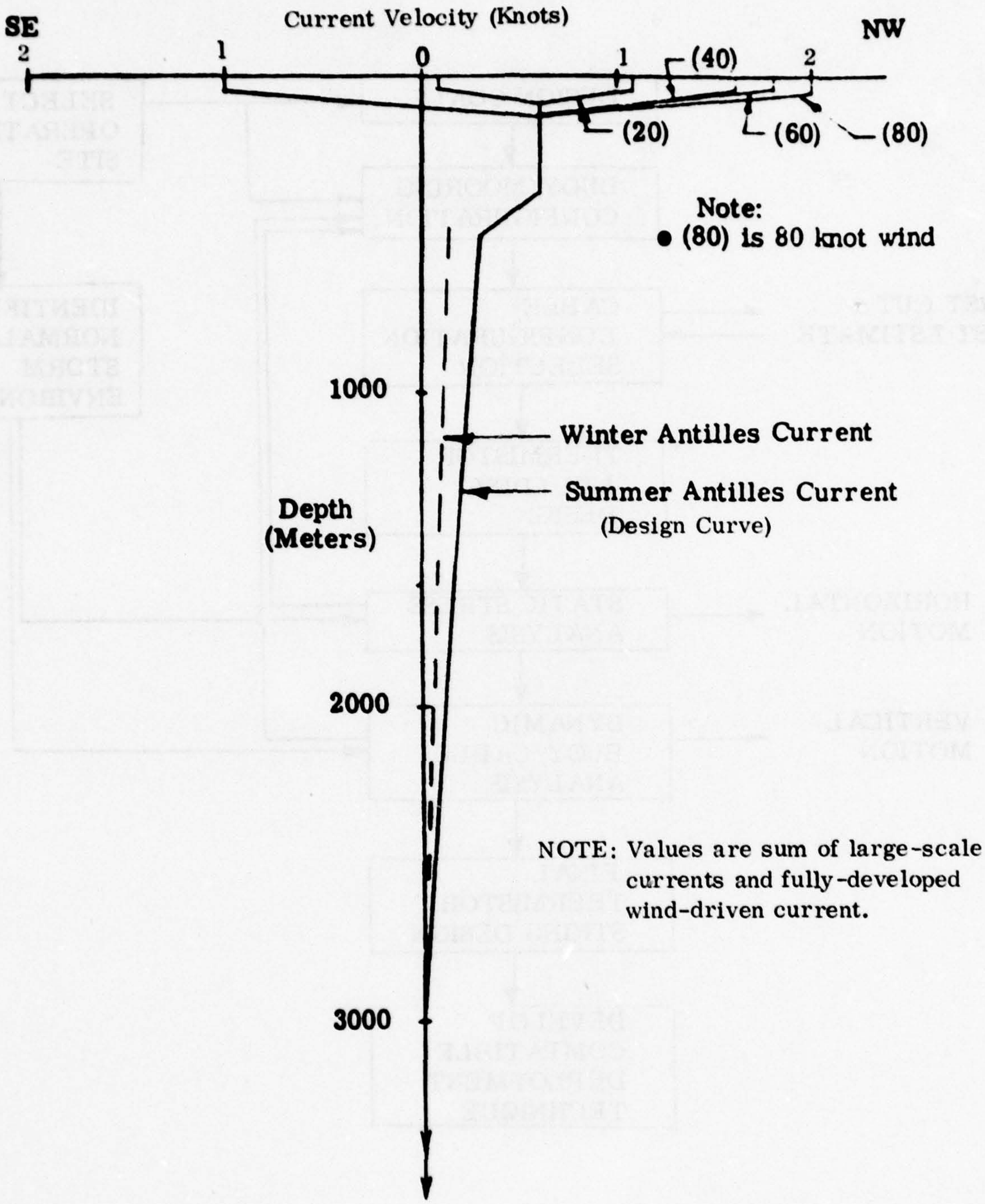


Figure 6 Current Profiles Used For Design Purposes.

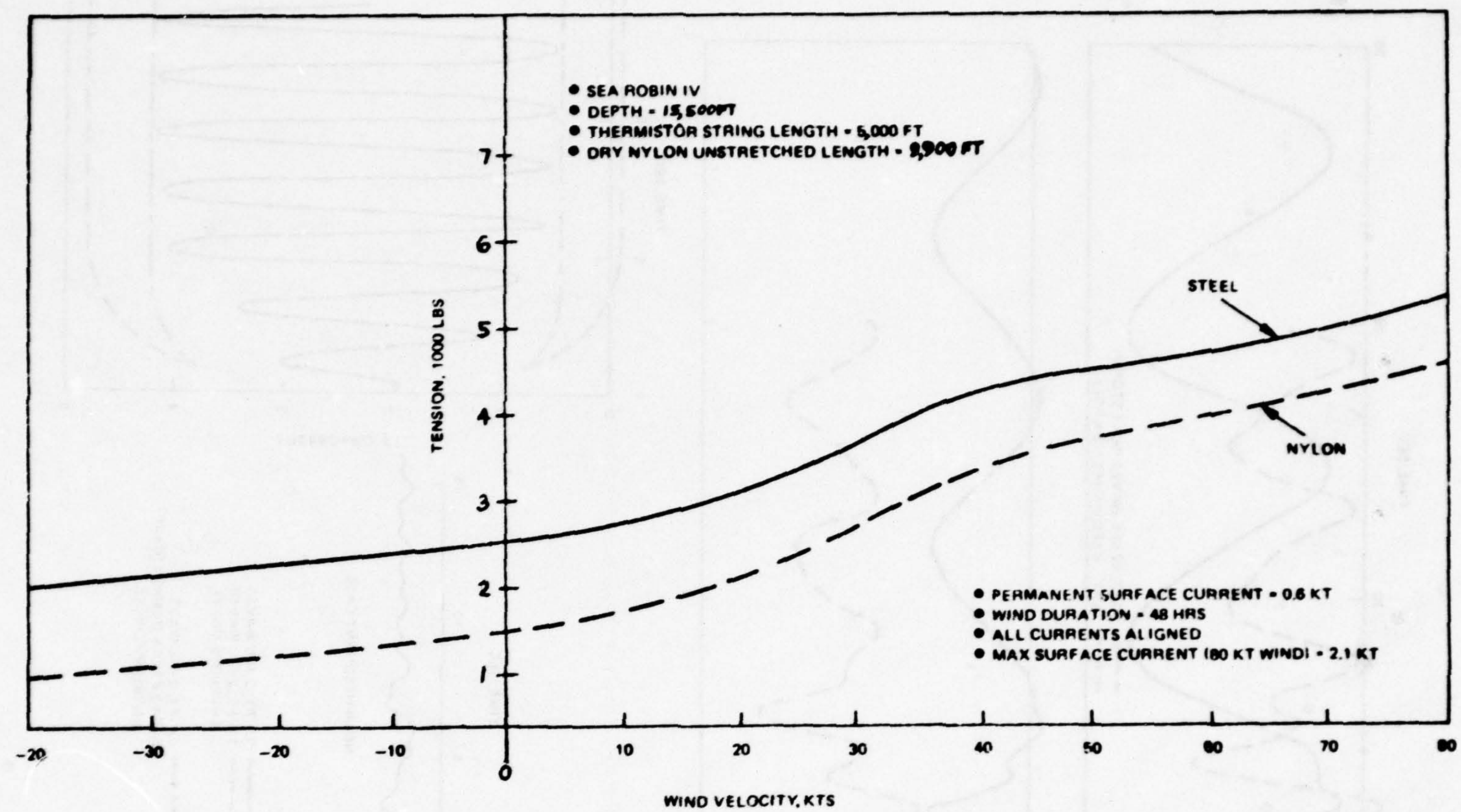


Figure 7 Static Mooring Loads As A Function Of Wind.

45

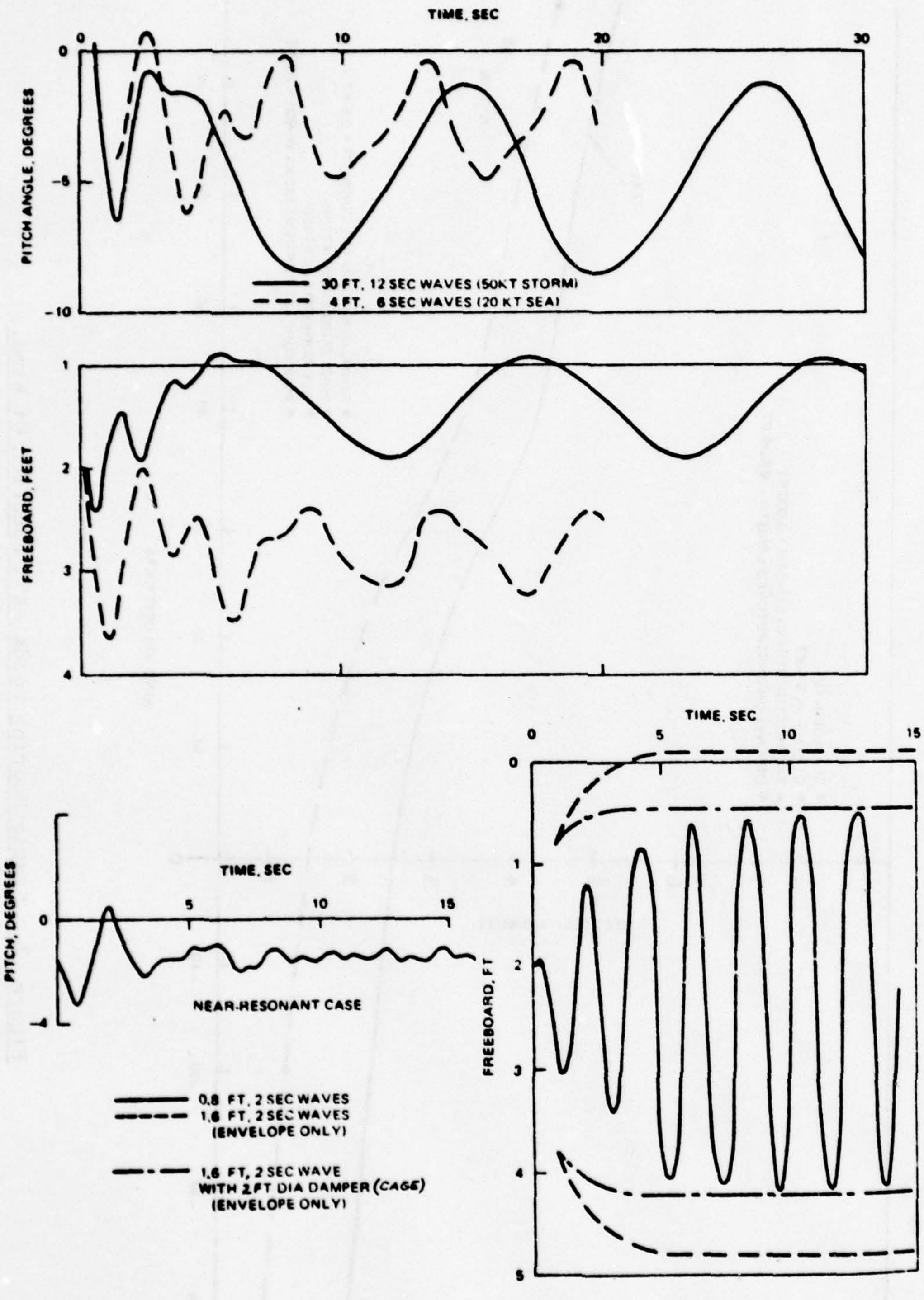


Figure 8 Buoy Dynamics Calculations.

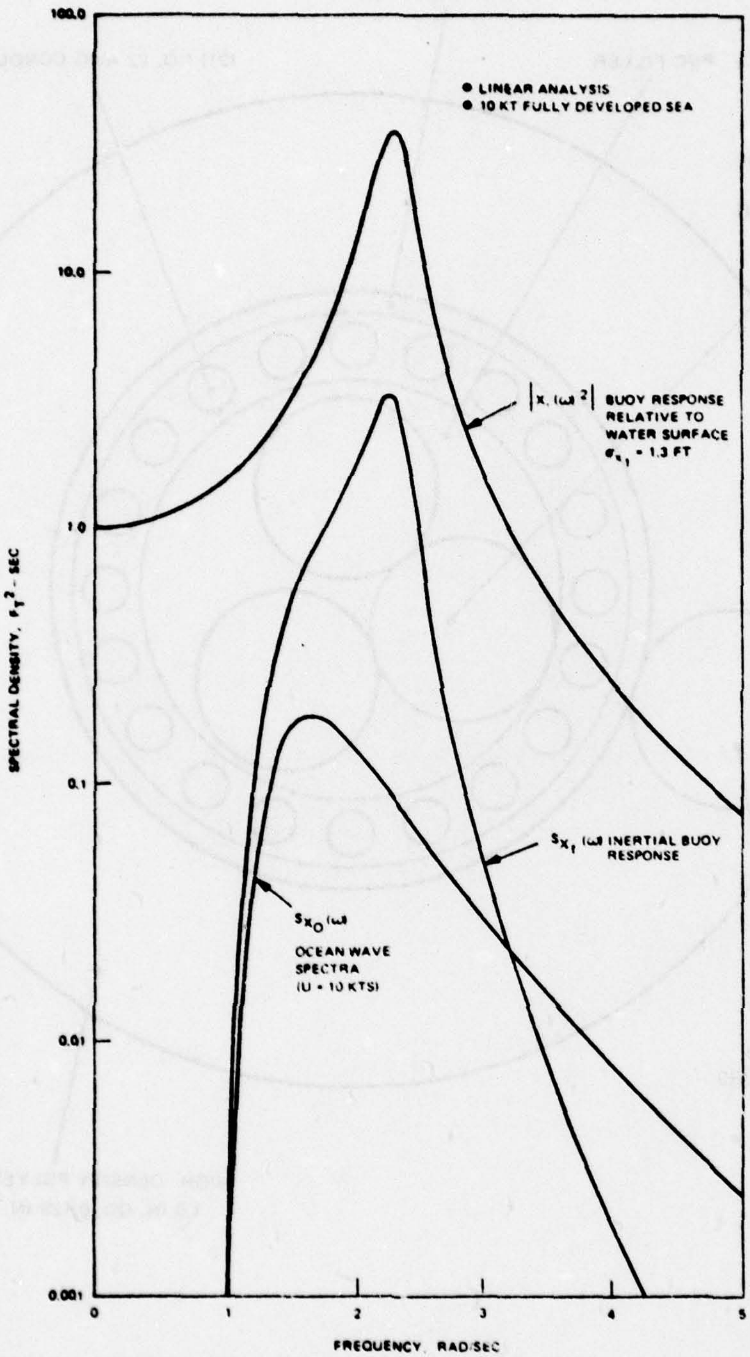


Figure 9. Sea Robin IV Heave Response.

47

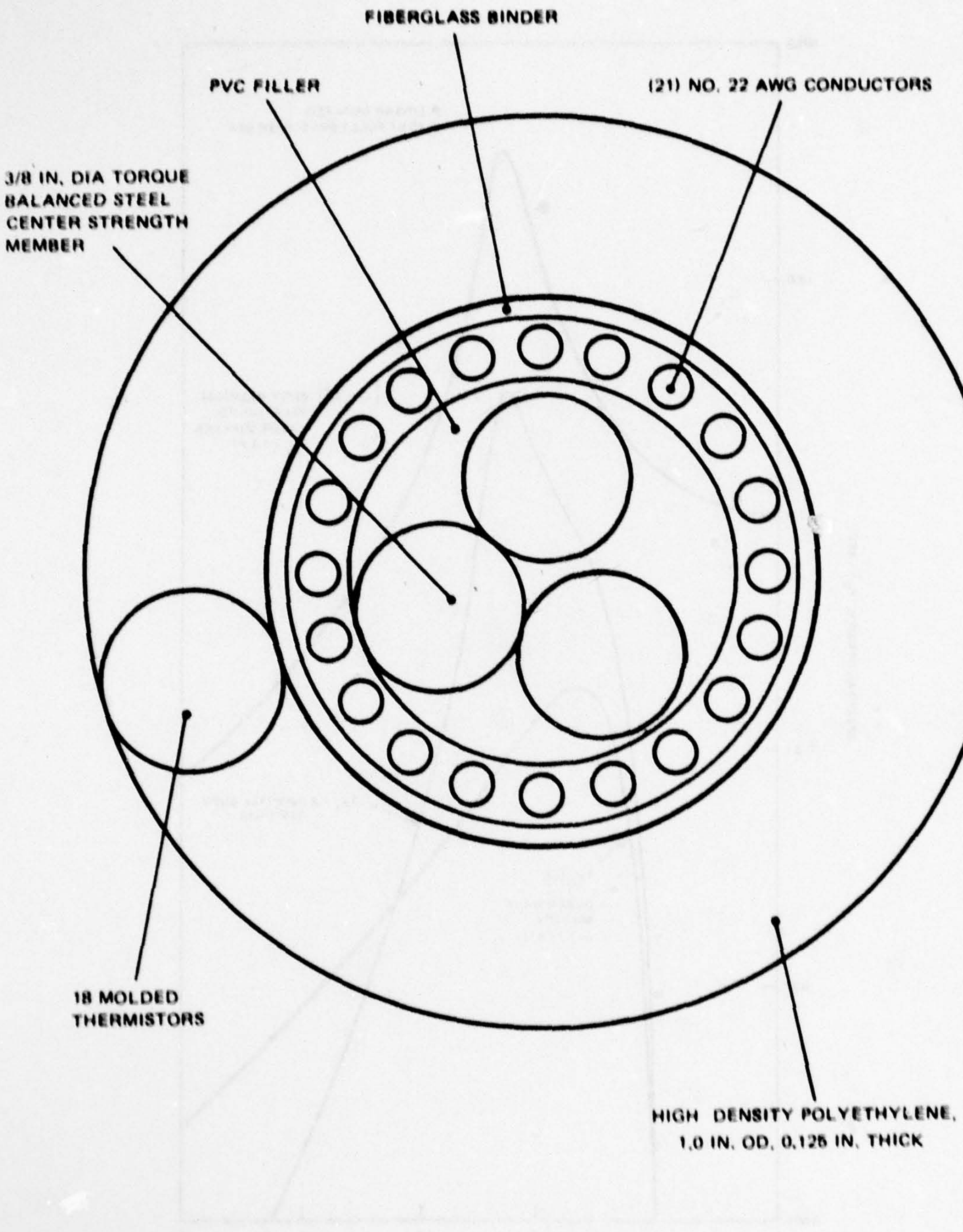


Figure 10 Thermistor String Cross Section.

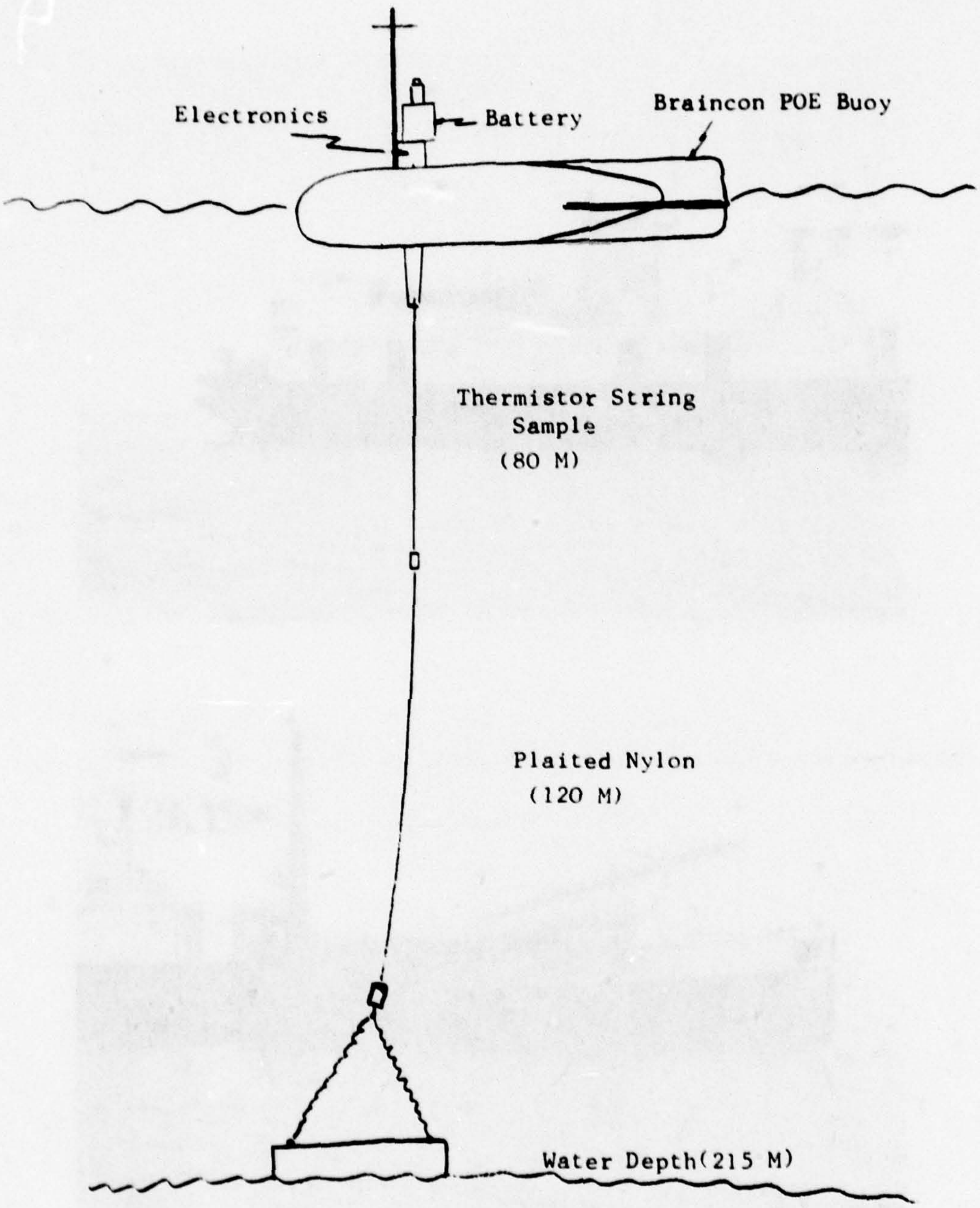


Figure 11 Short Term Test Of Thermistor String (Miami)

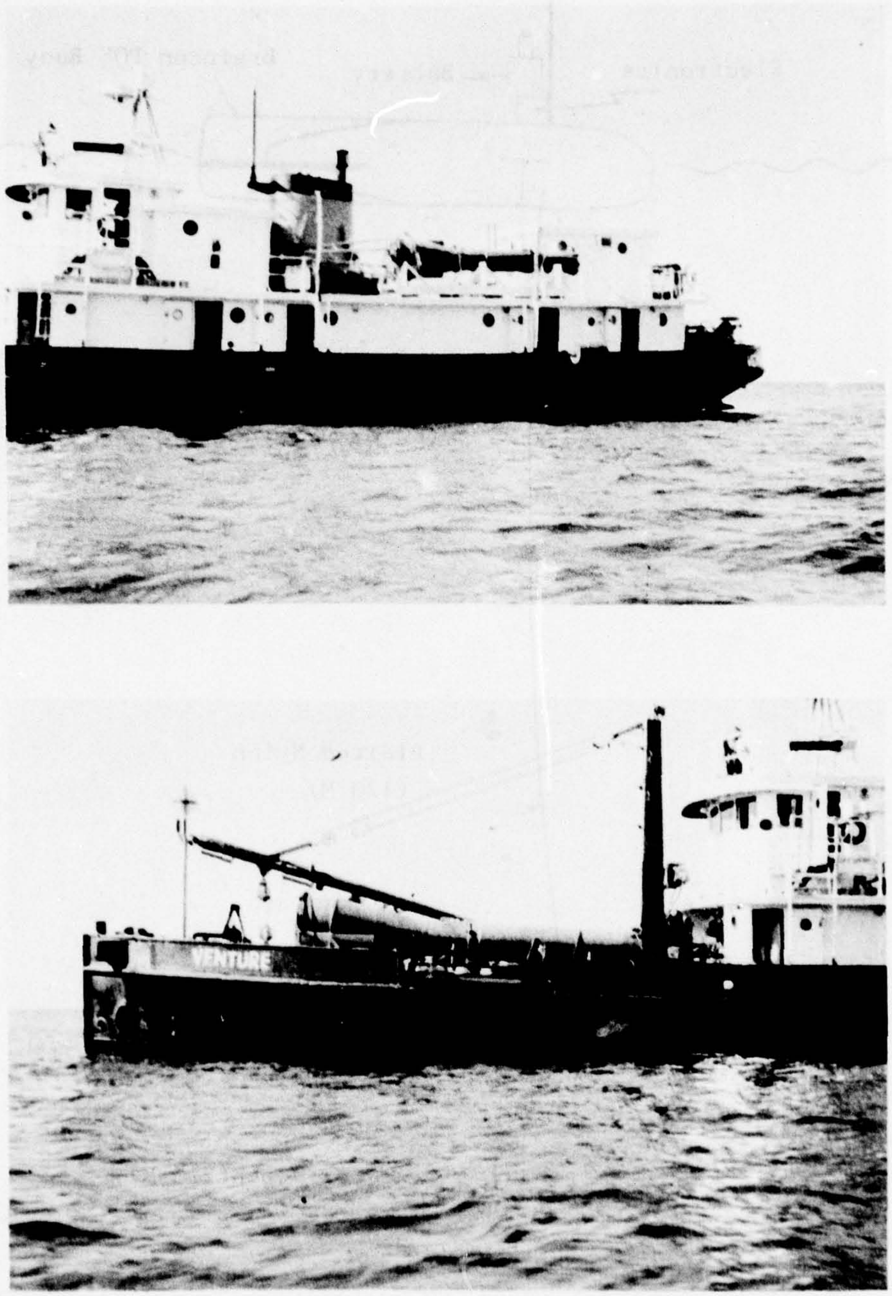


Figure 12 Sea Robin III and Sea Robin IV Before Deployment

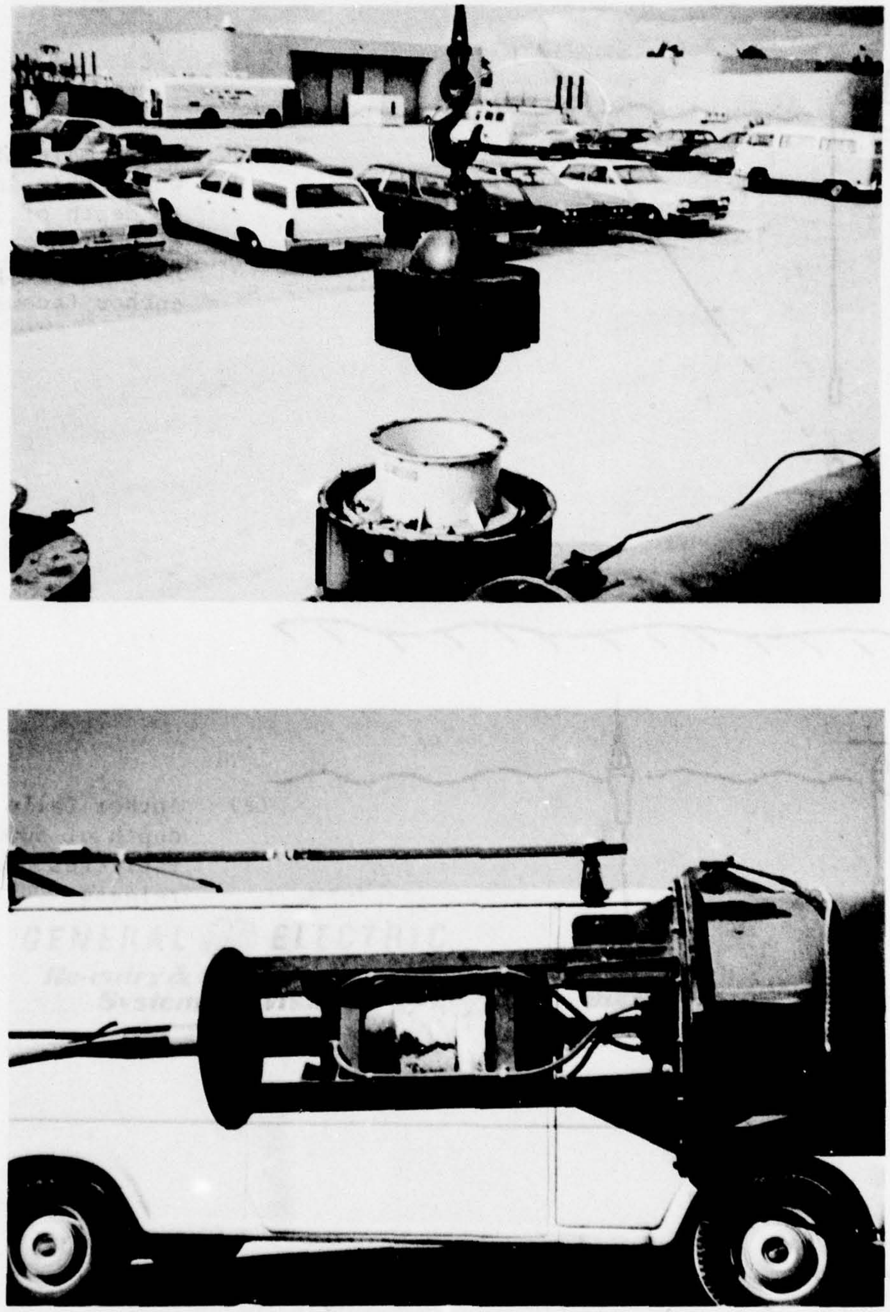
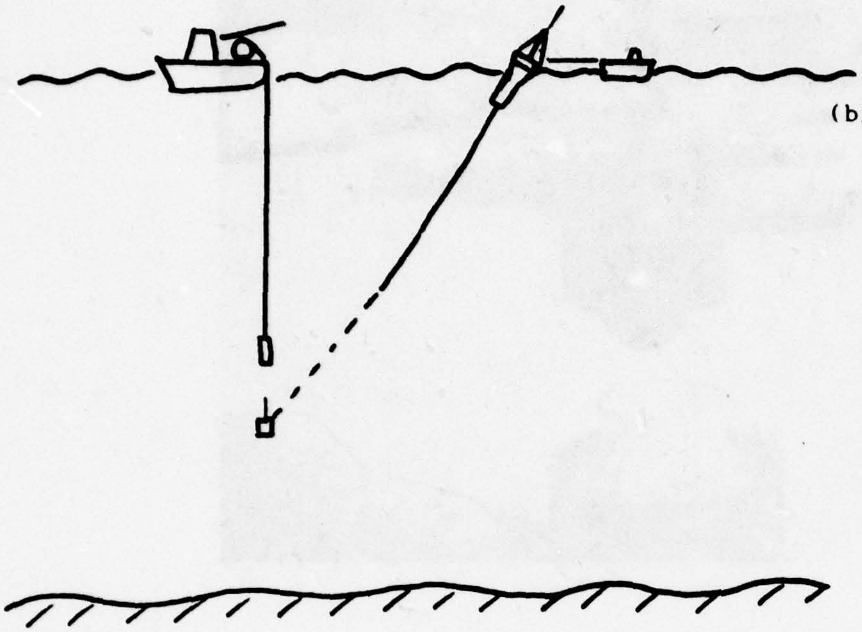
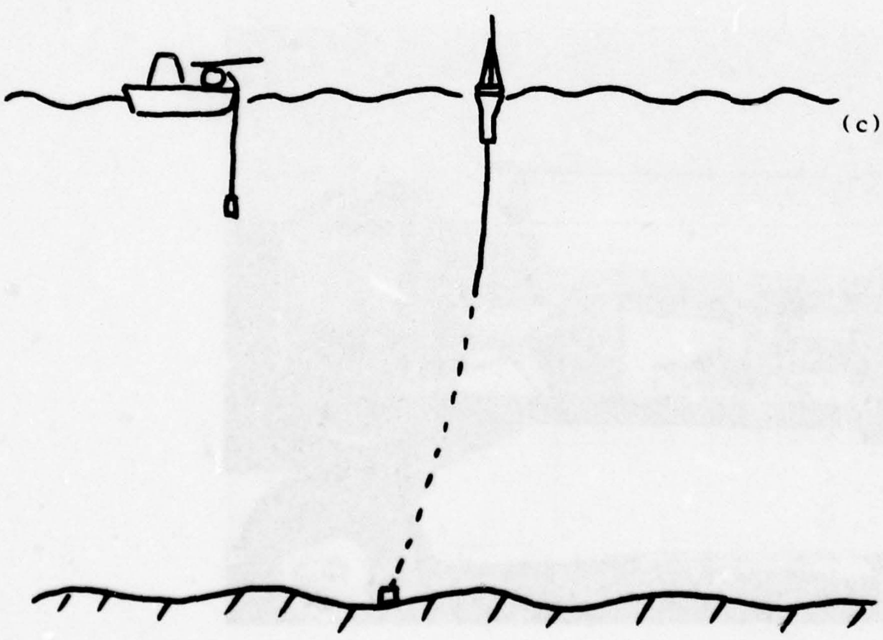


Figure 13 Staging The Radioisotopic Power Generator(RPG)

(a) Skiff tows buoy while ship deploys thermistor string and assemblies.

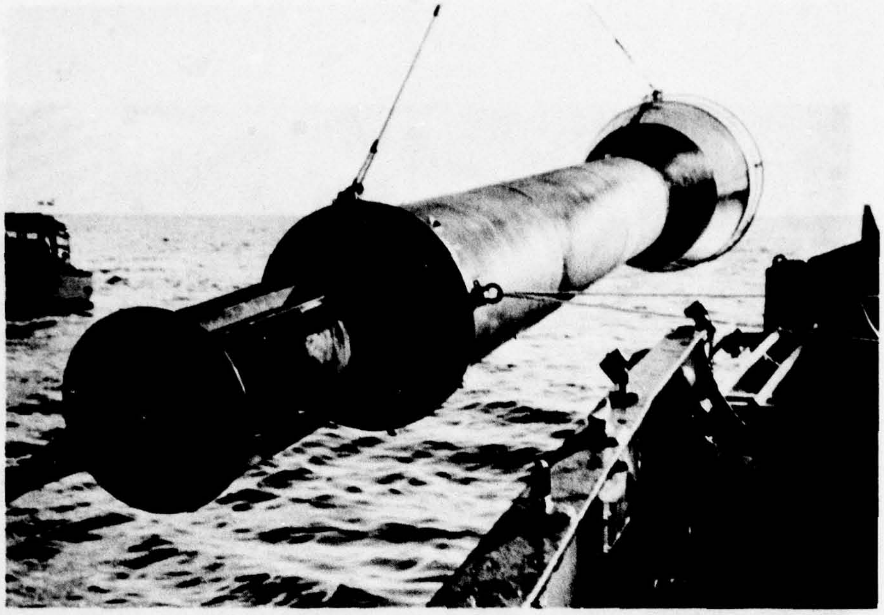


(b) Skiff maintains separation while ship lowers anchor to depth of 3400 M on crown line. Skiff releases buoy and ship releases anchor (acoustic release).



(c) Anchor falls to final depth of 5000M while ship retrieves crown line and release.

Figure 14 Deployment Sequence For Sea Robin IV.



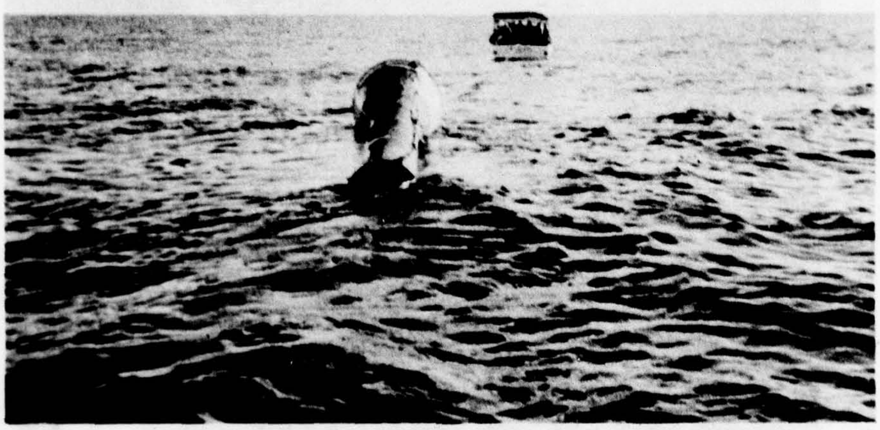


Figure 15 Sea Robin IV During Overboarding And Under Tow.

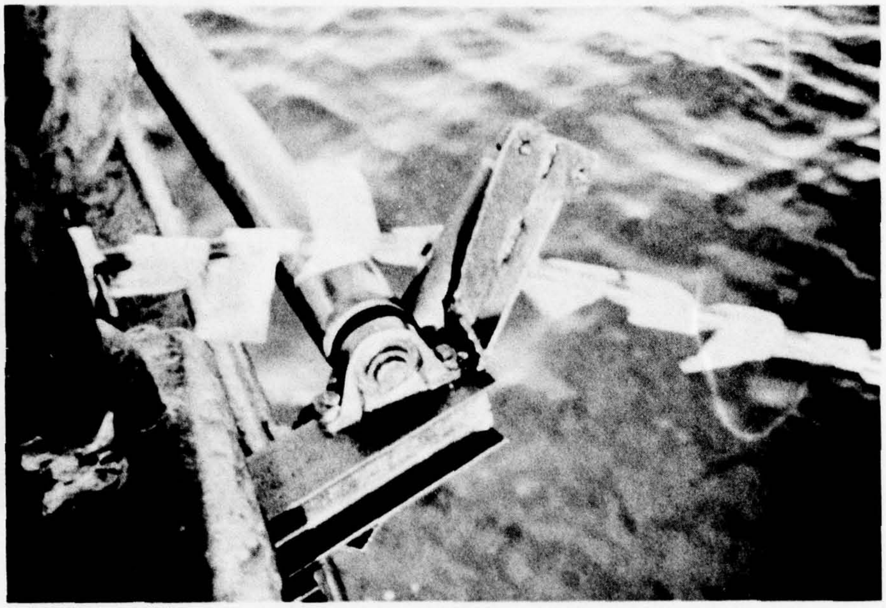


Figure 16 Deployment Of The Faired Thermistor String.

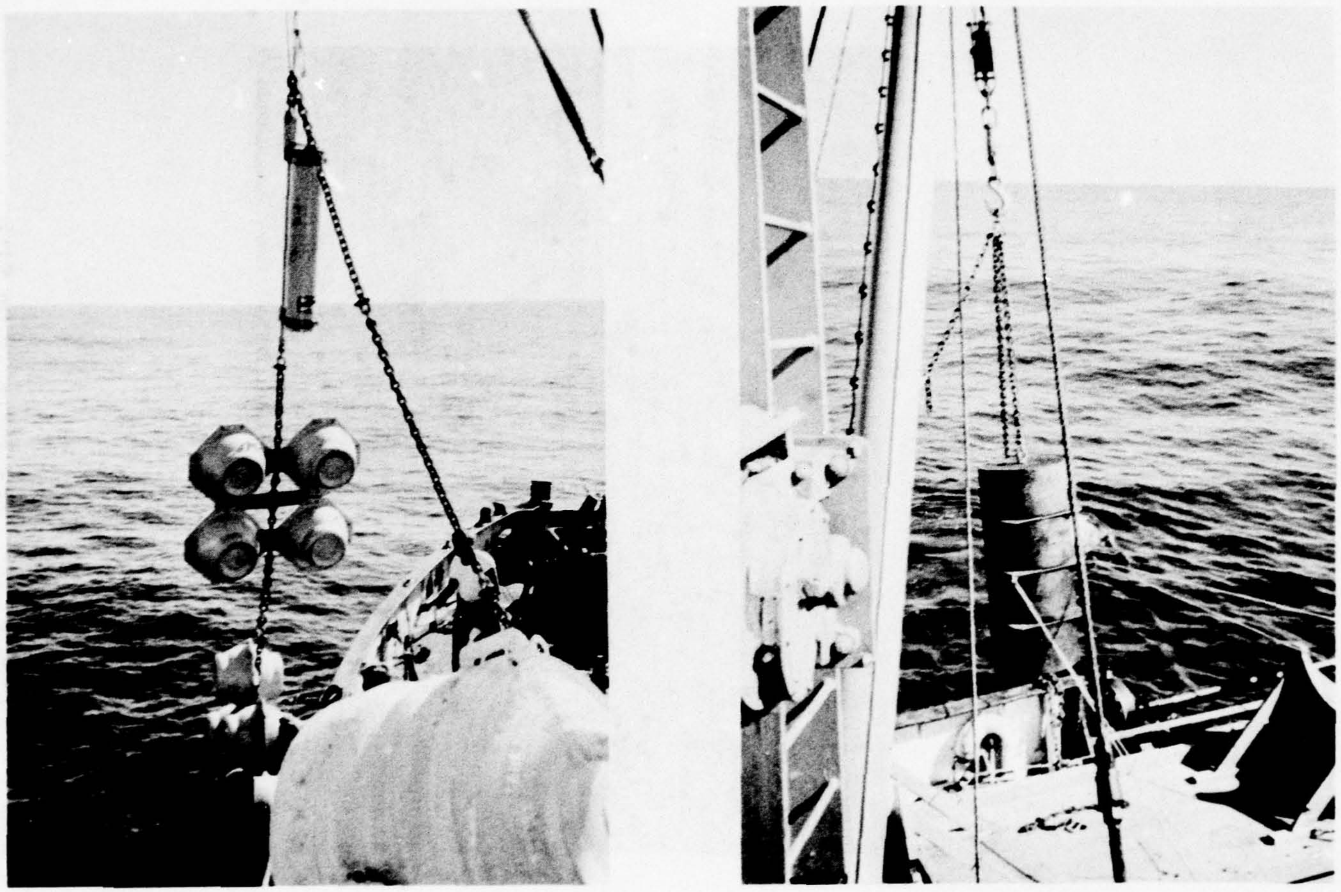


Figure 17 Overboarding The Acoustic Release System (Left) And The Deadweight Anchor (Right)

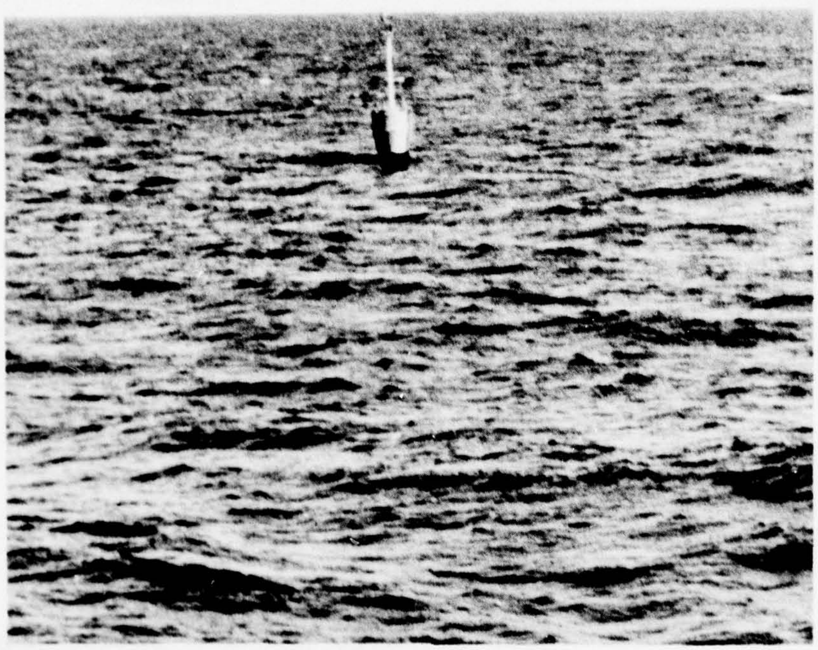


Figure 18 Sea Robin IV On Site

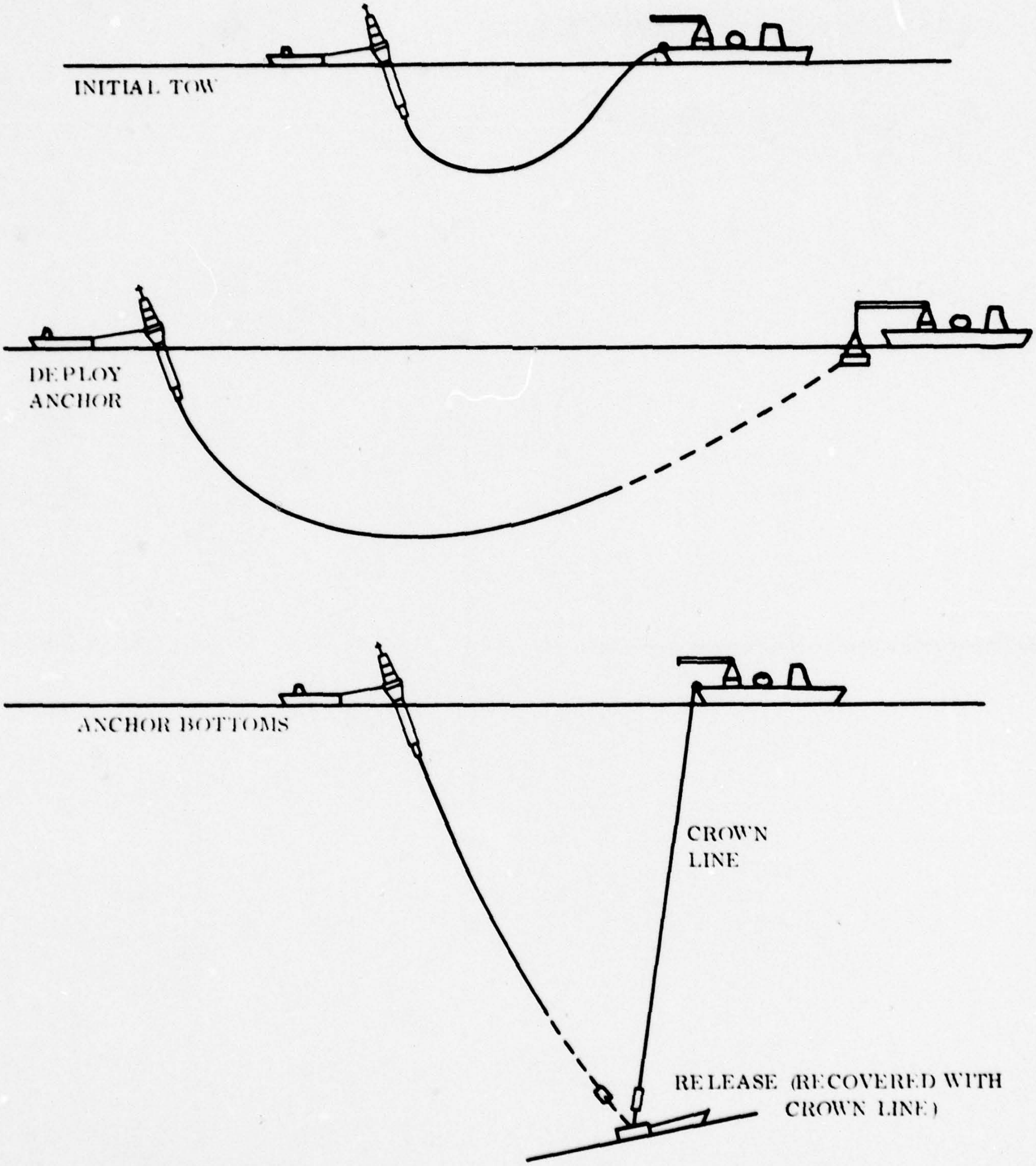
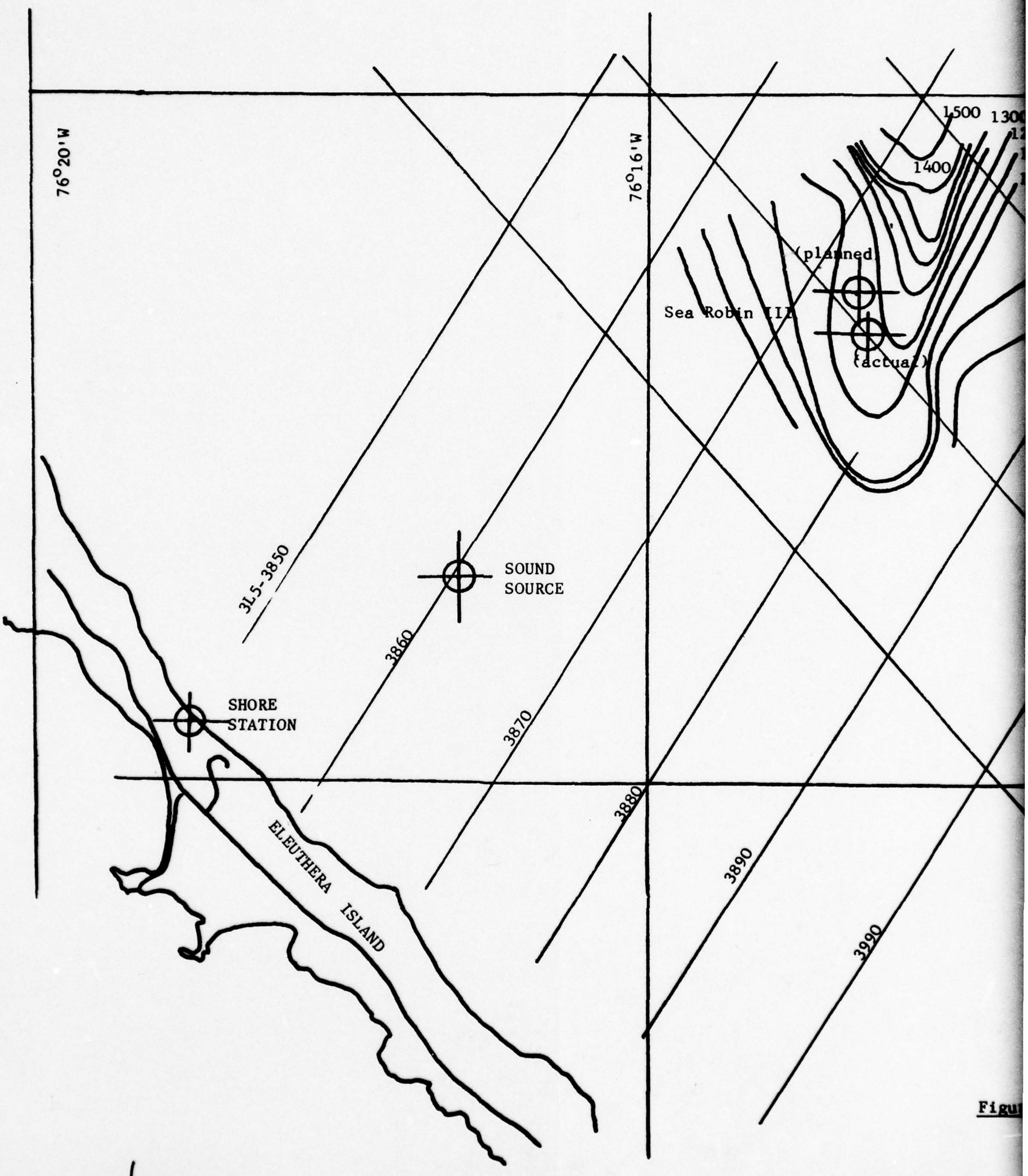


Figure 19 Deployment Sequence For Sea Robin III.



76°20'W
76°16'W
1500
1300
1400
(planned)
Sea Robin III
(actual)
3L5-3850
SOUND
SOURCE
3860
SHORE
STATION
3870
3880
ELEUTHERA
ISLAND
3890
3990

Figu

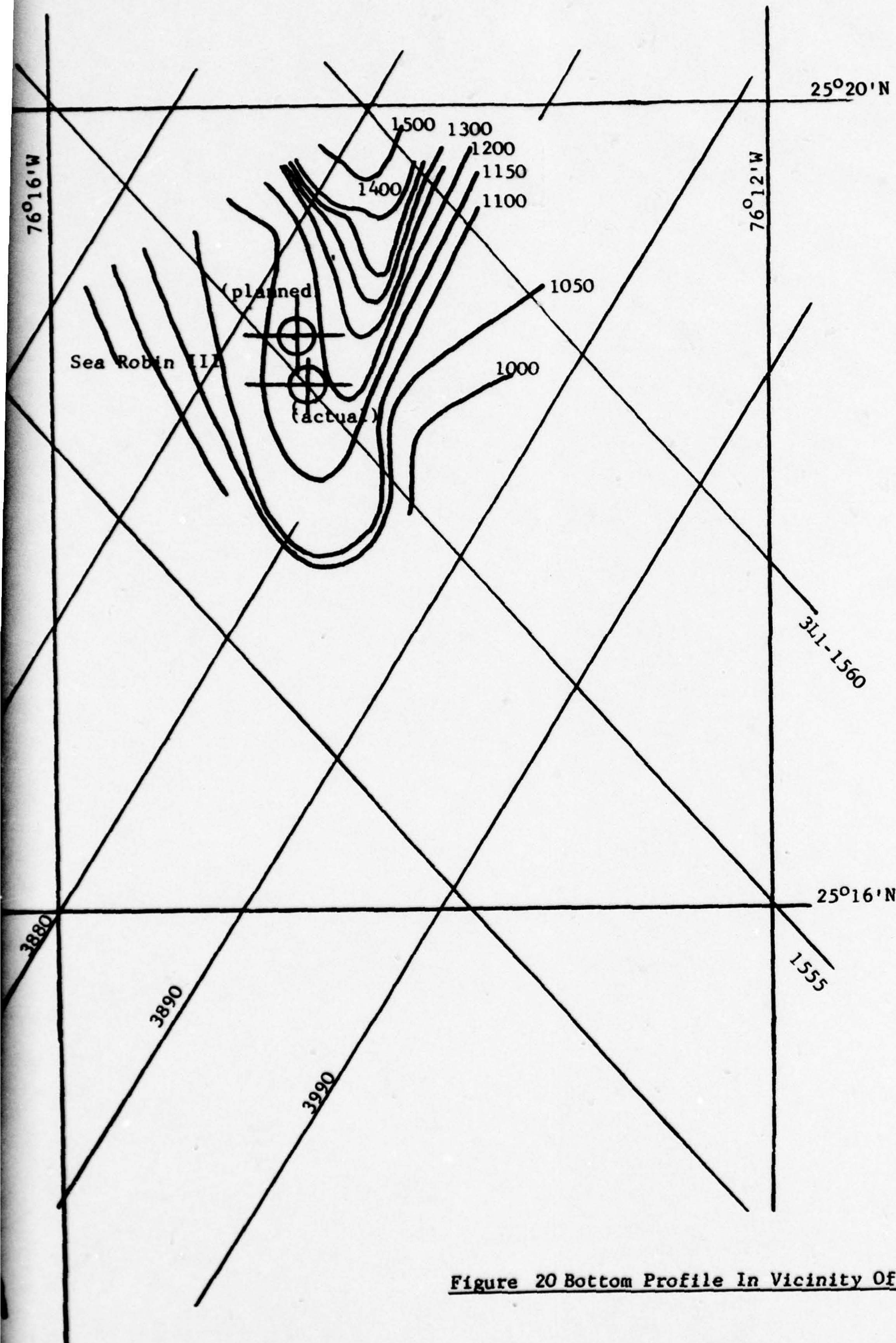


Figure 20 Bottom Profile In Vicinity Of Sea Robin III.

57 2

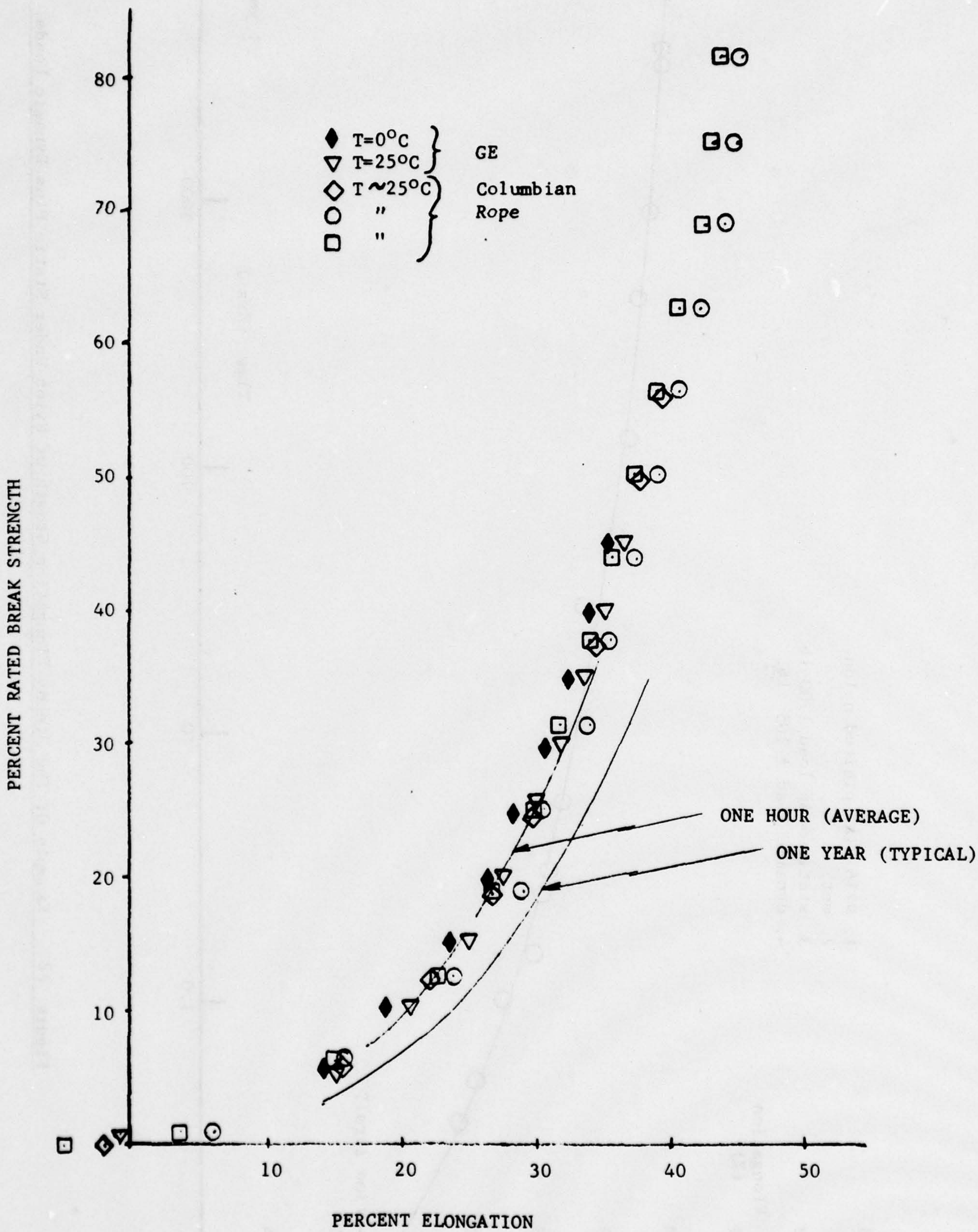


Figure 21 Nylon Load Elongation Characteristics.

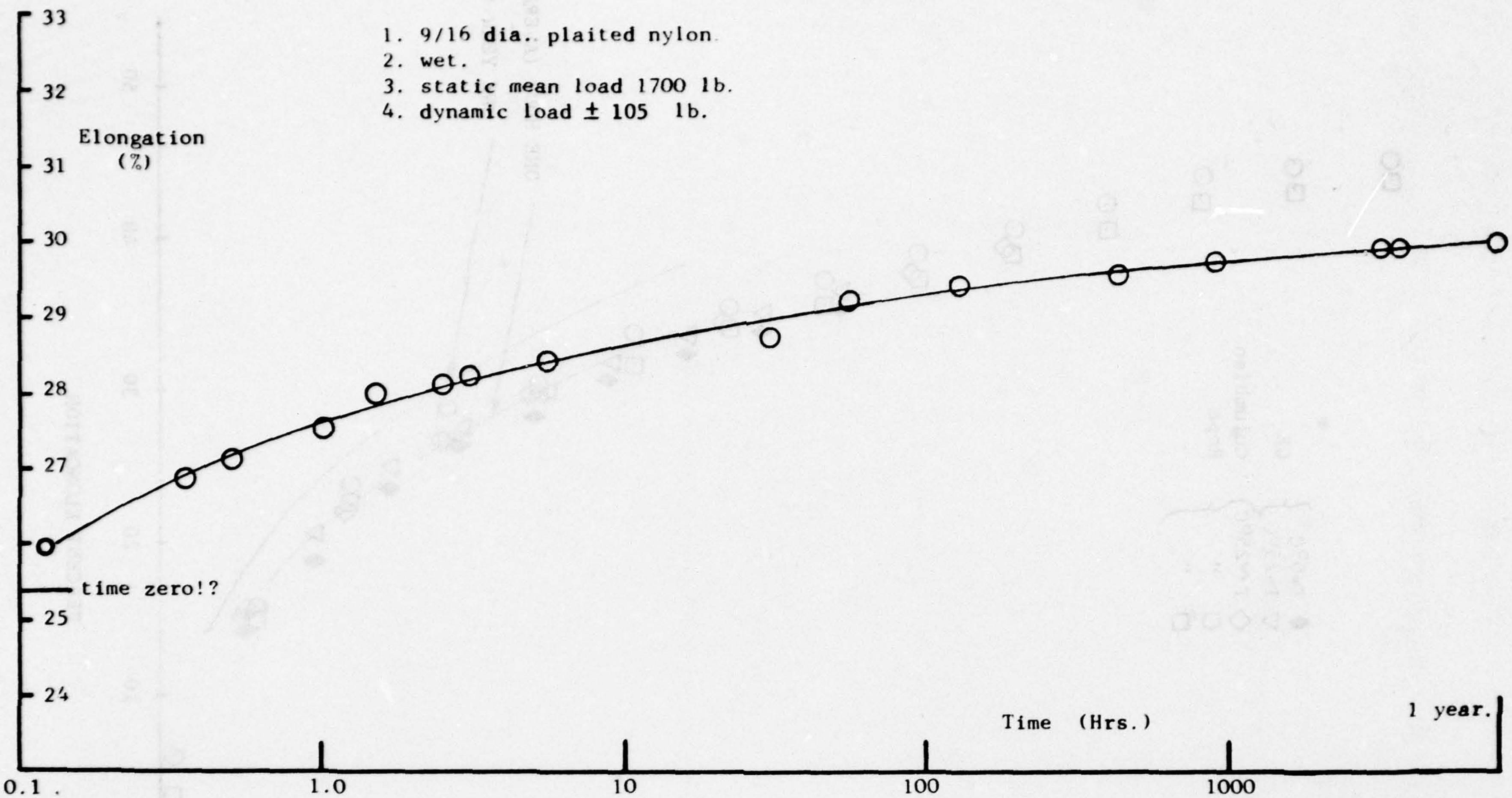


Figure 22 Example Of The Steady Elongation Growth Of Nylon Under Static Plus Dynamic Loads.

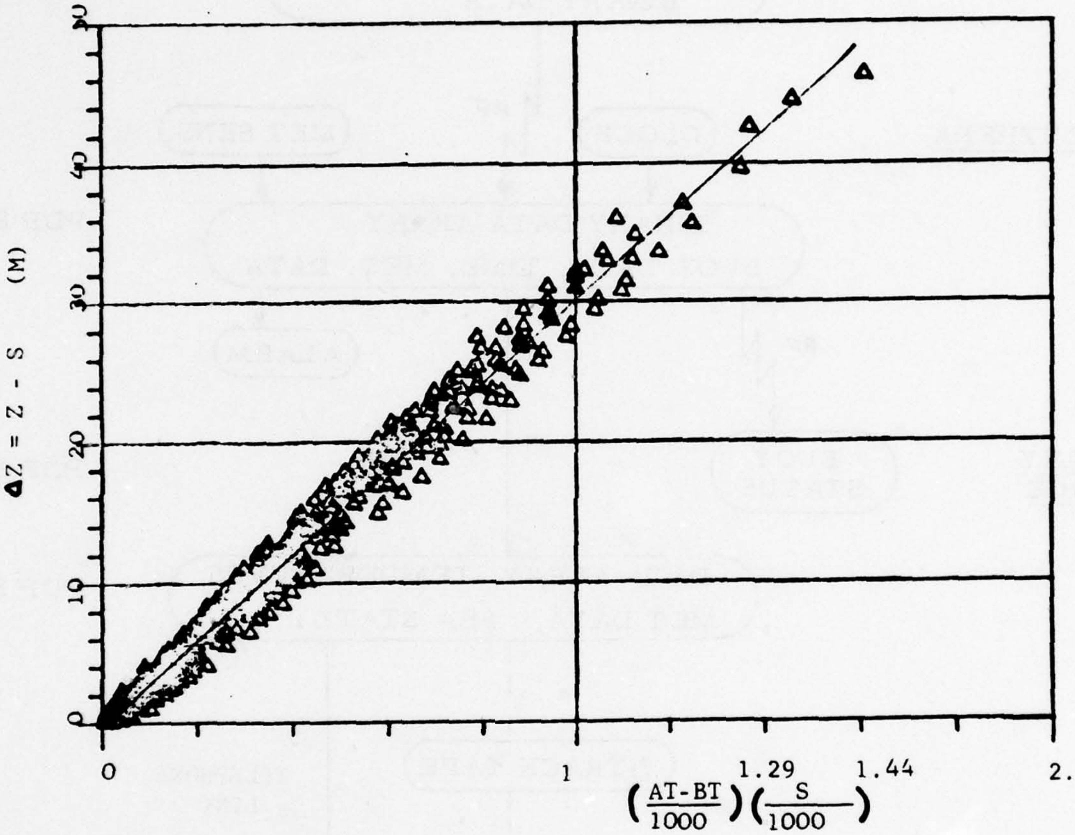


Figure 23. Depth Correction Of Thermisters As A Function Of Tension

62

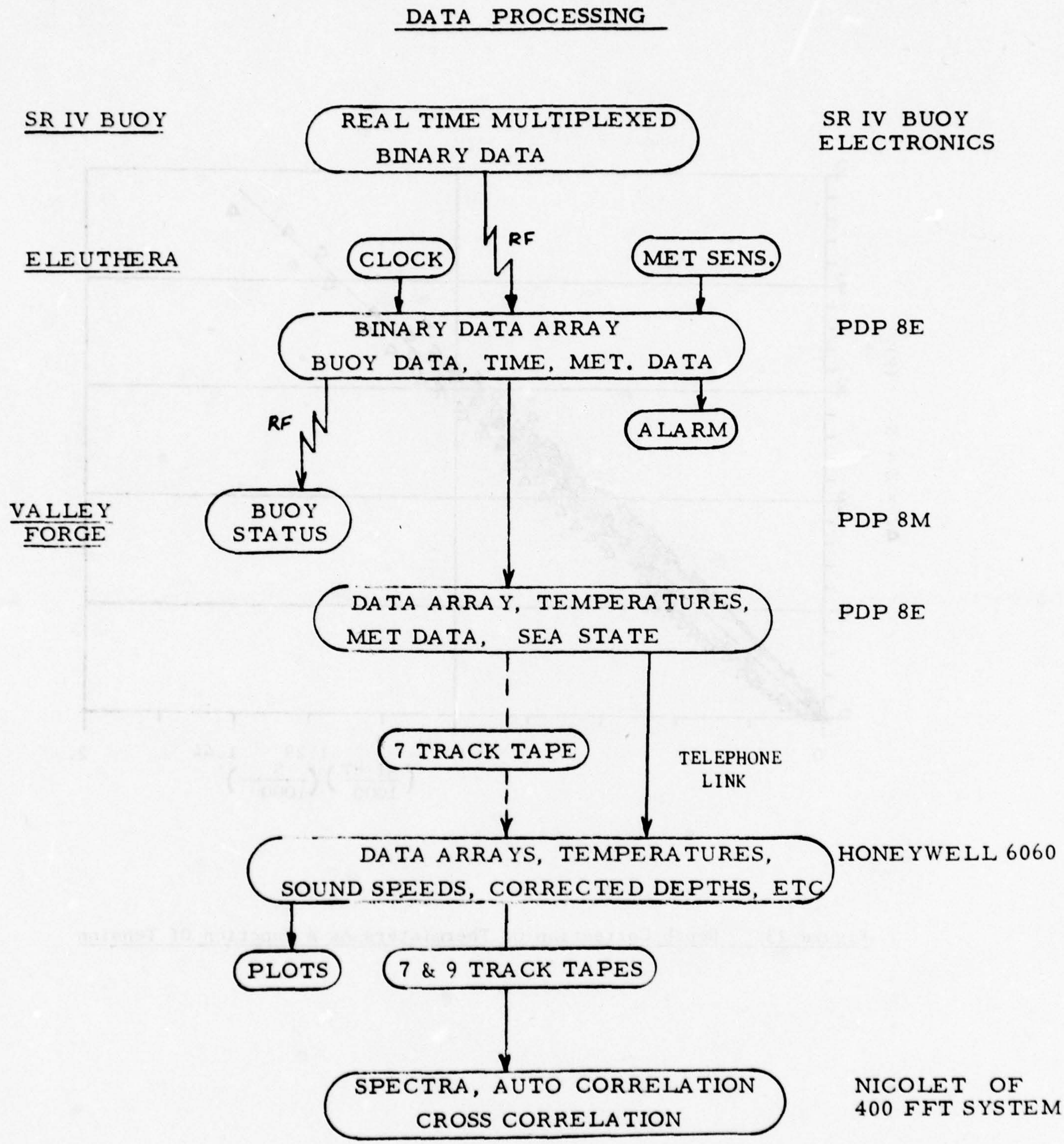
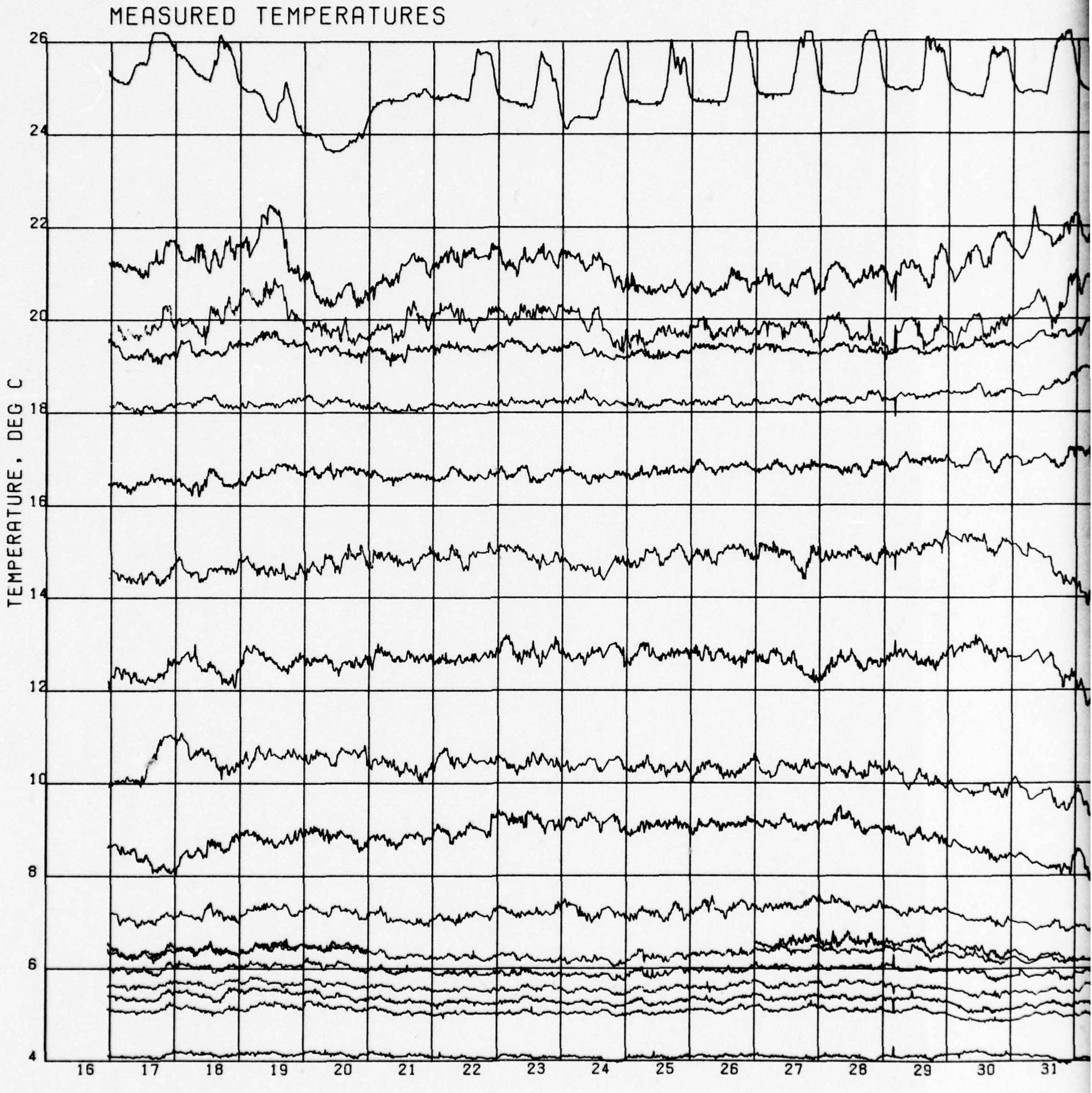
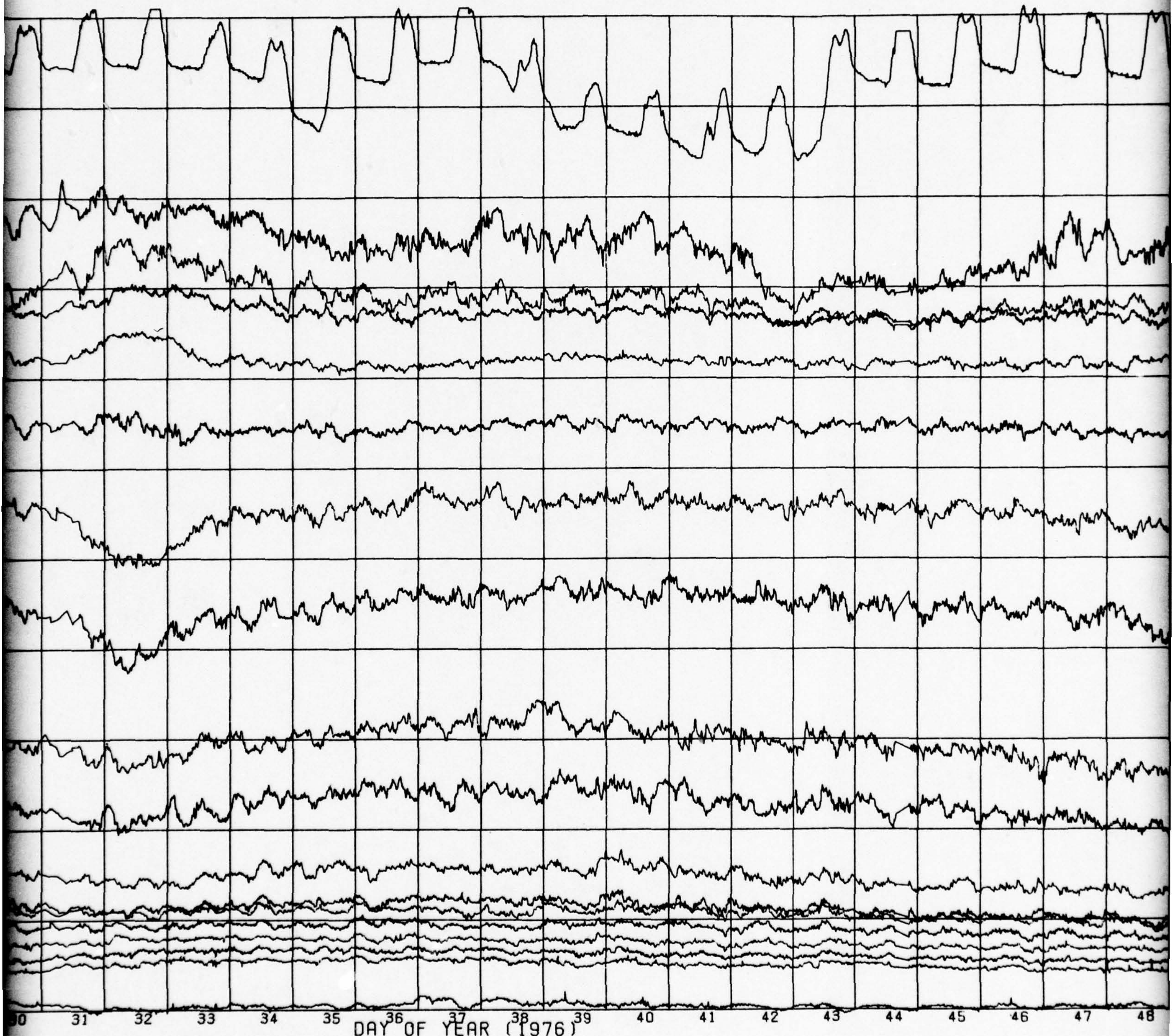


Figure 24 Data Processing Flow Summary.



MEASURED TEMPERATURES
TEMPERATURE, DEG C
26
24
22
20
18
16
14
12
10
8
6
4
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31

1



30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
DAY OF YEAR (1976)

Figur

2

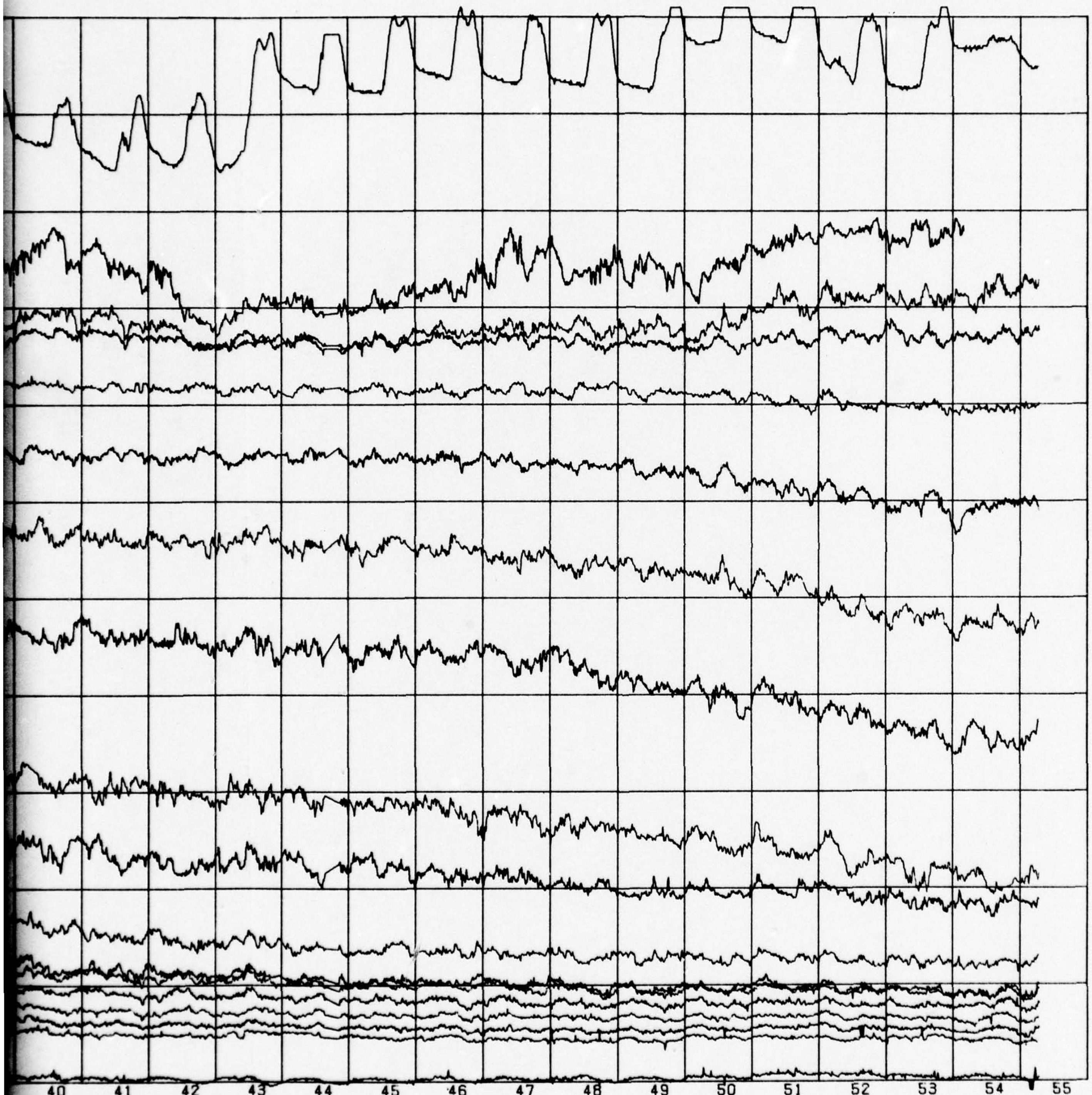
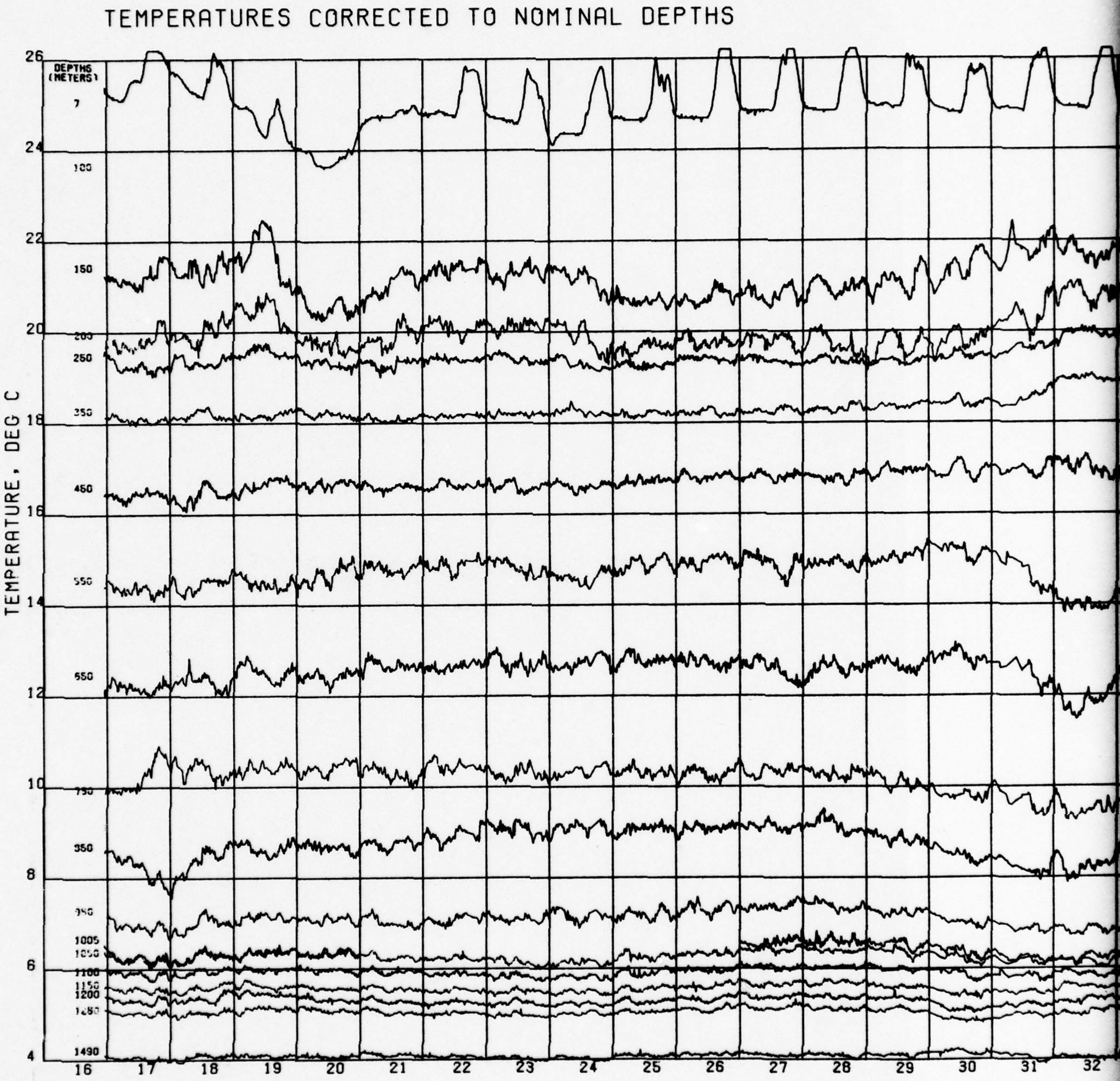


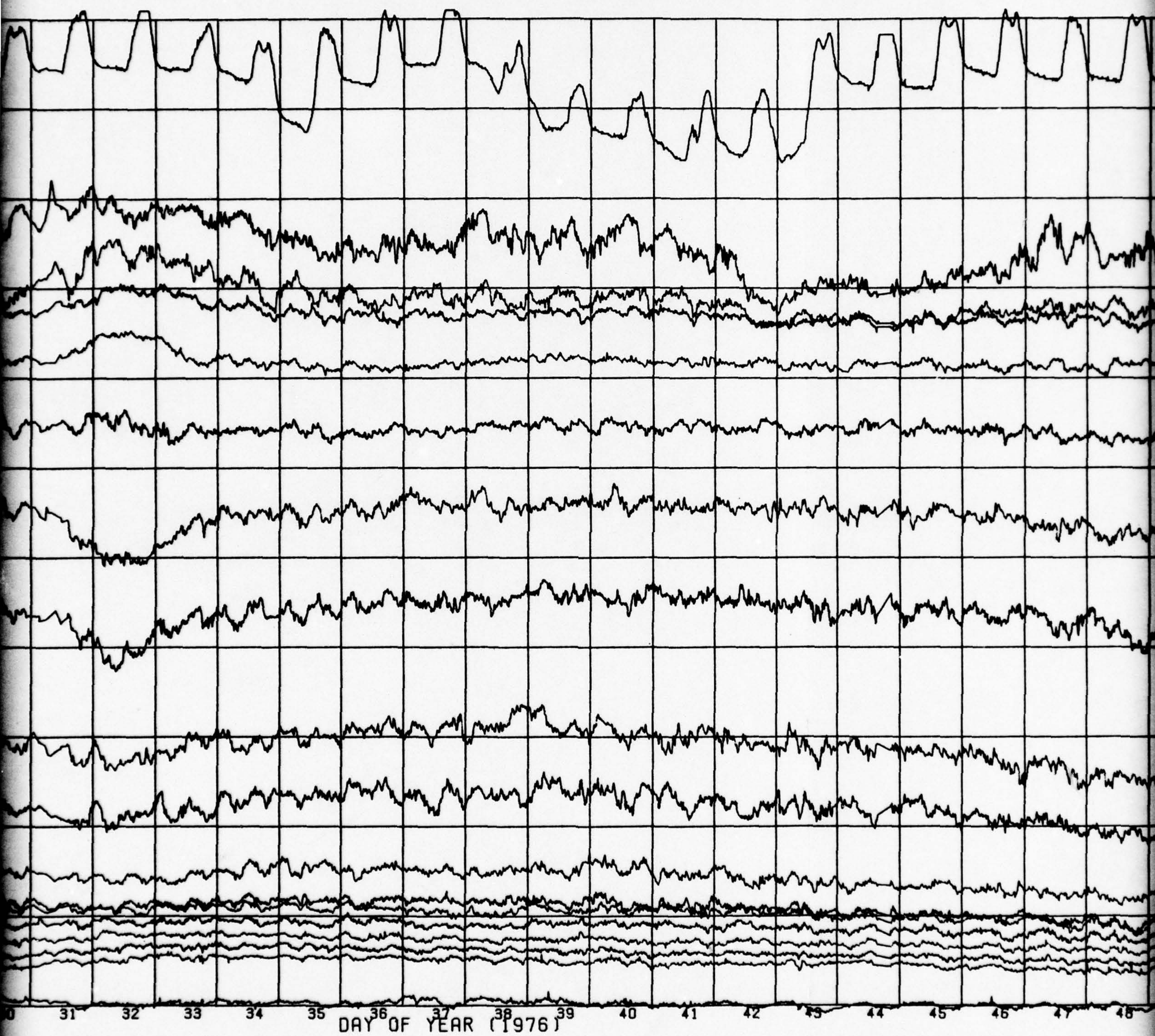
Figure 25. Measured Temperatures (Sea Robin IV)

65

3


TEMPERATURES CORRECTED TO NOMINAL DEPTHS
TEMPERATURE, DEG C
DEPTHS (METERS)
7
100
150
200
250
350
450
550
650
750
850
950
1005
1050
1100
1150
1200
1250
1490
26
24
22
20
18
16
14
12
10
8
6
4
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32

1



30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
DAY OF YEAR (1976)

Figure 26.

7

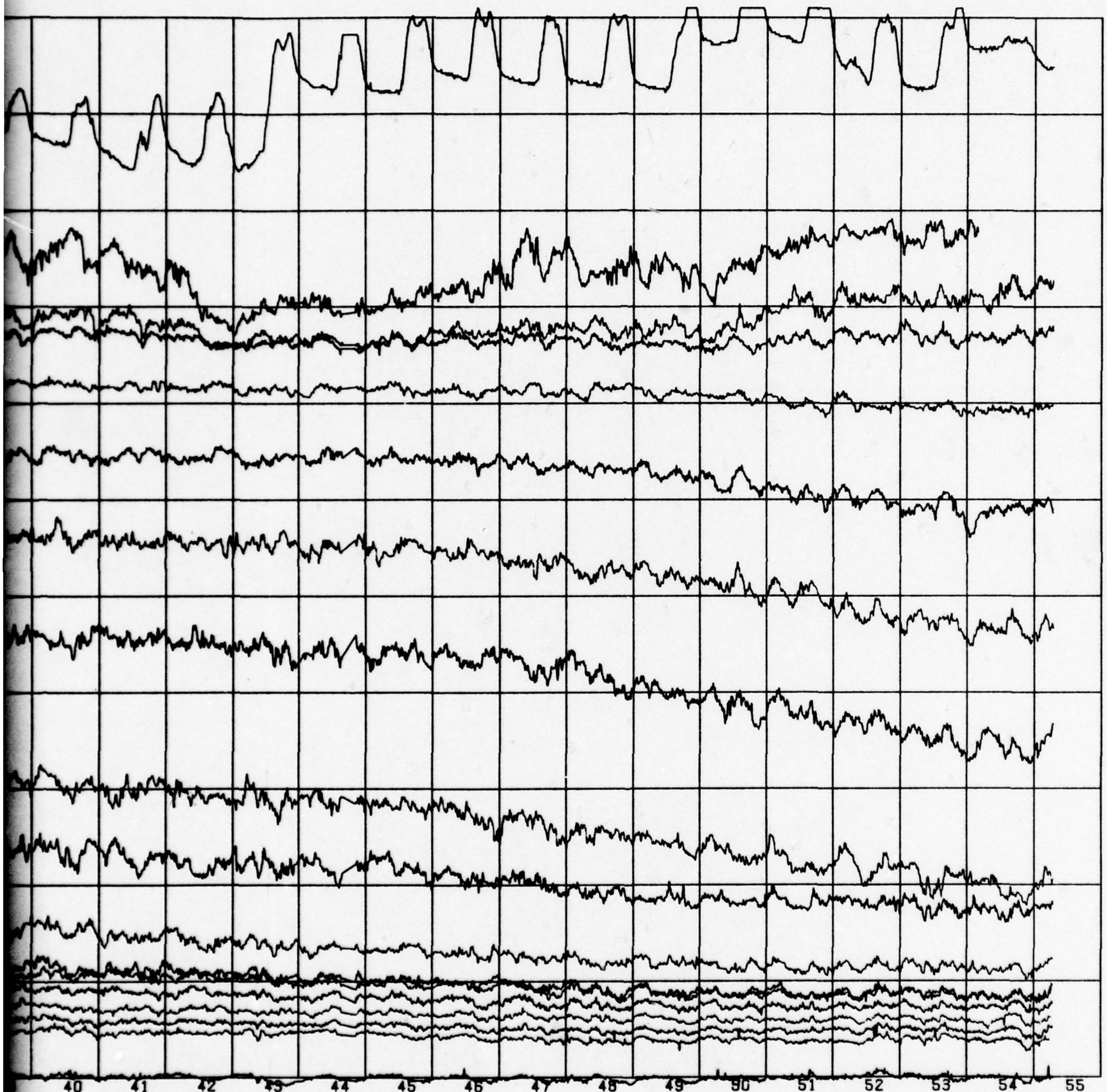
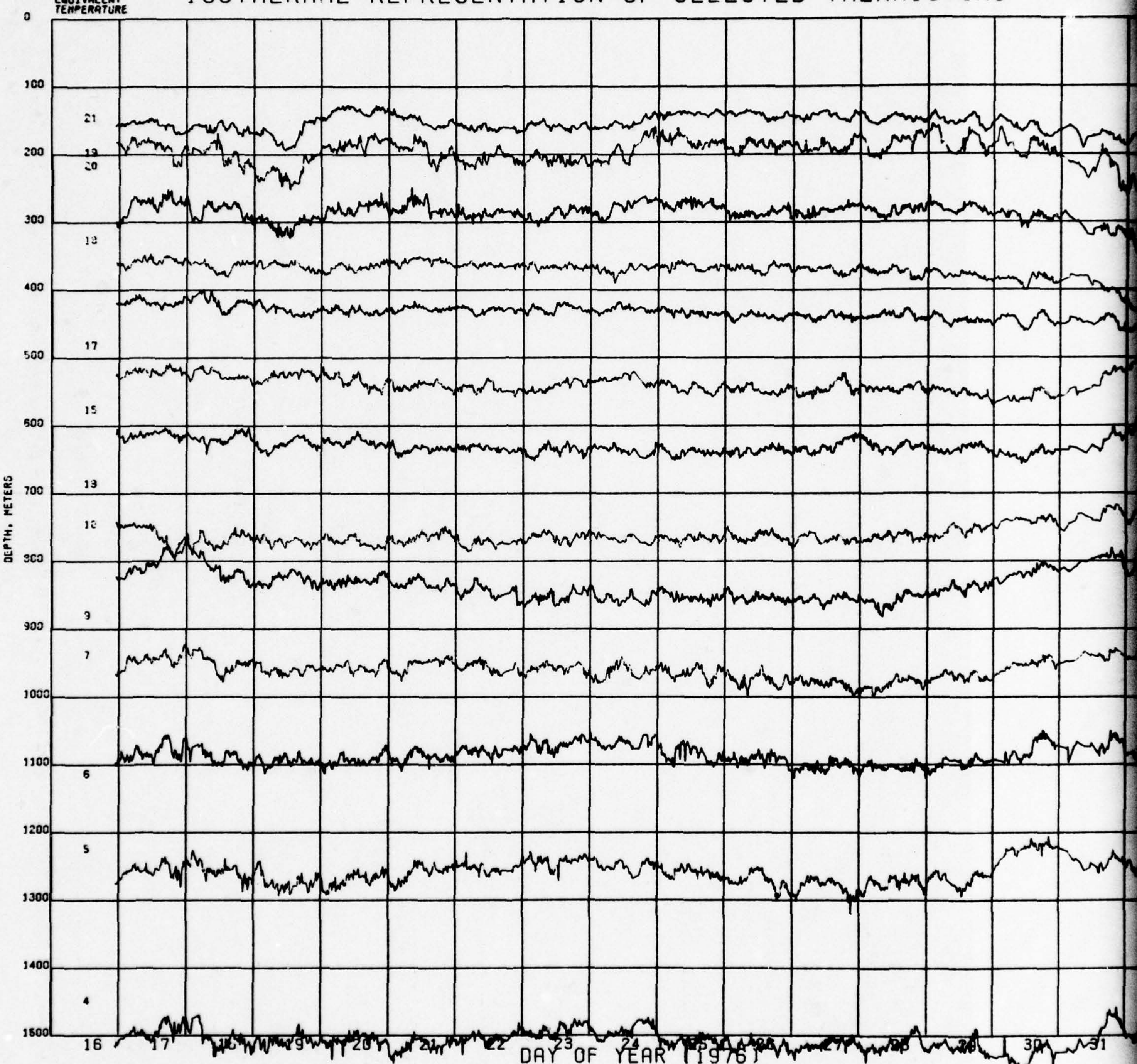


Figure 26. Temperatures Corrected To Constant Depth.

67 3

ISOTHERMAL REPRESENTATION OF SELECTED THERMISTORS



1

ORS

Figure

2

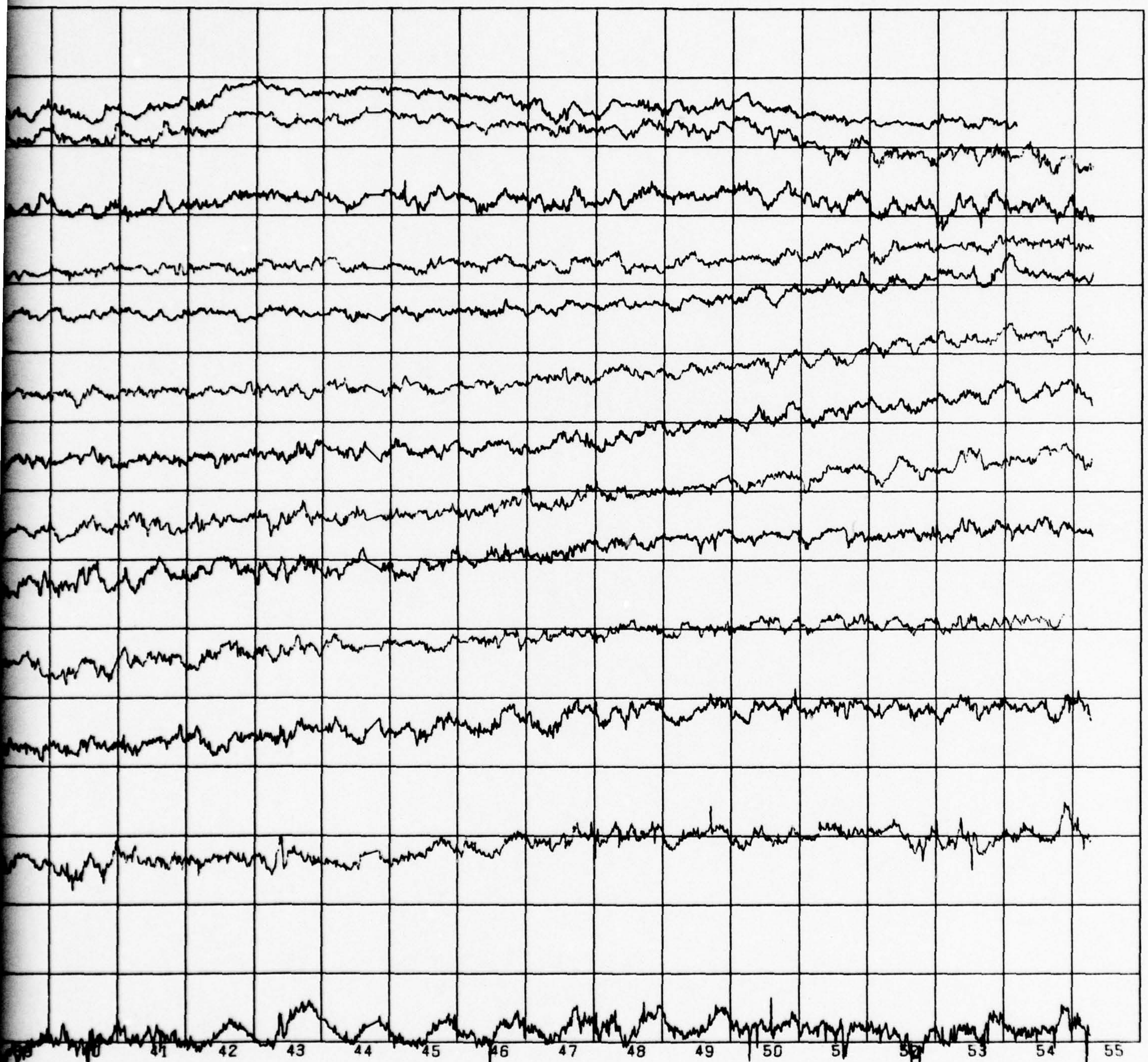
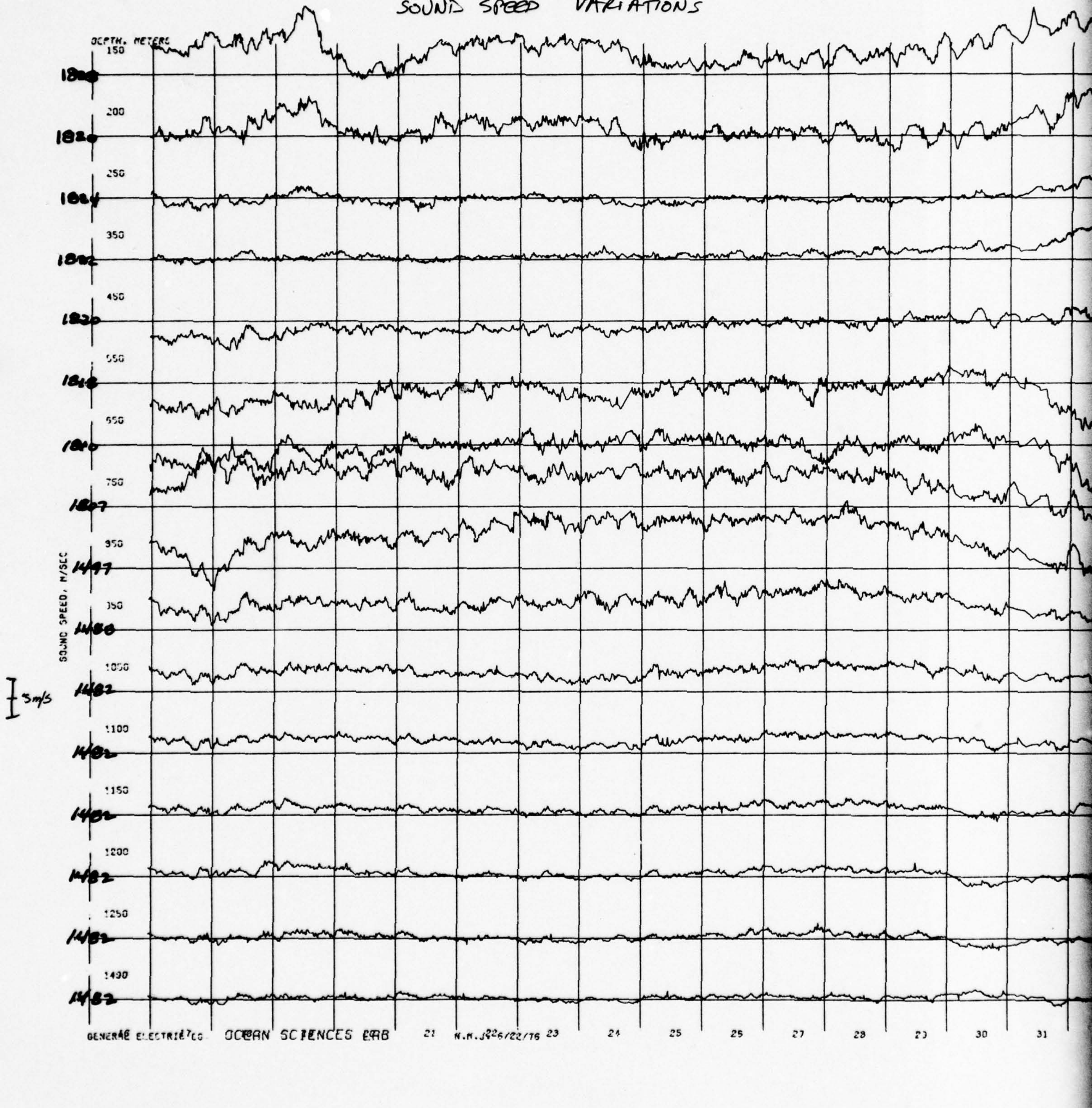


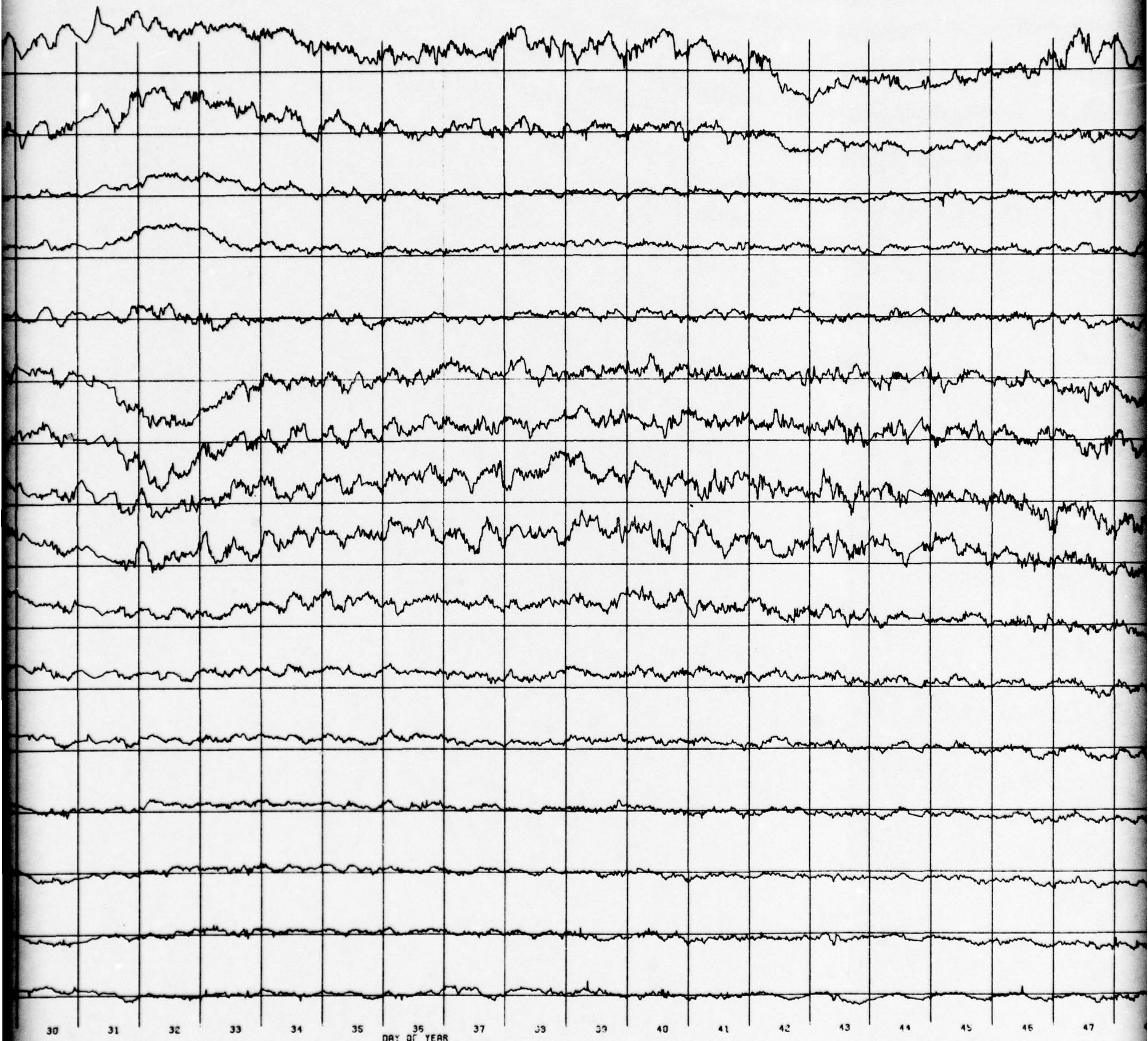
Figure 27, Isothermal Representation Of Thermisters.

69 3

SOUND SPEED VARIATIONS



1



2

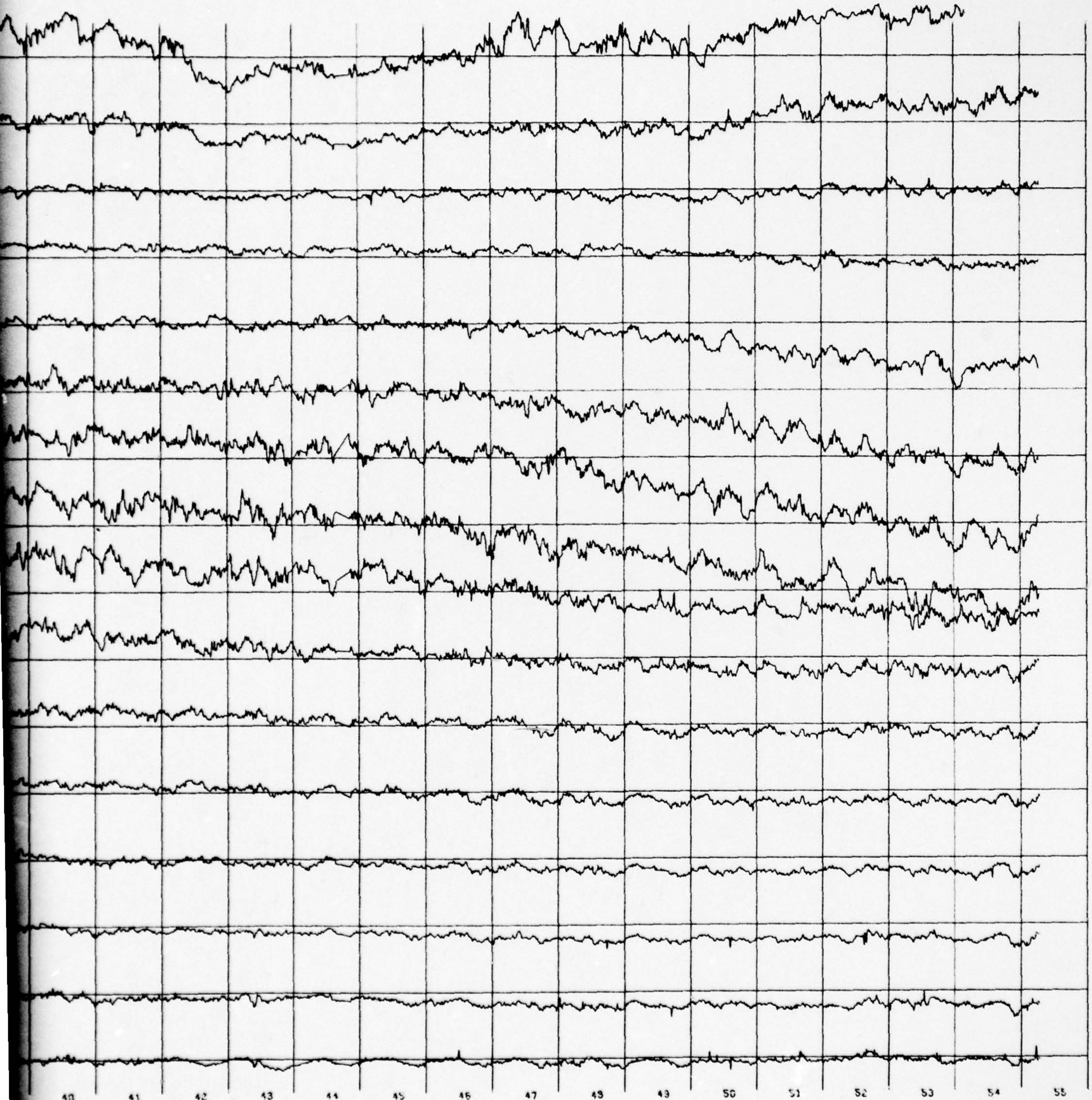
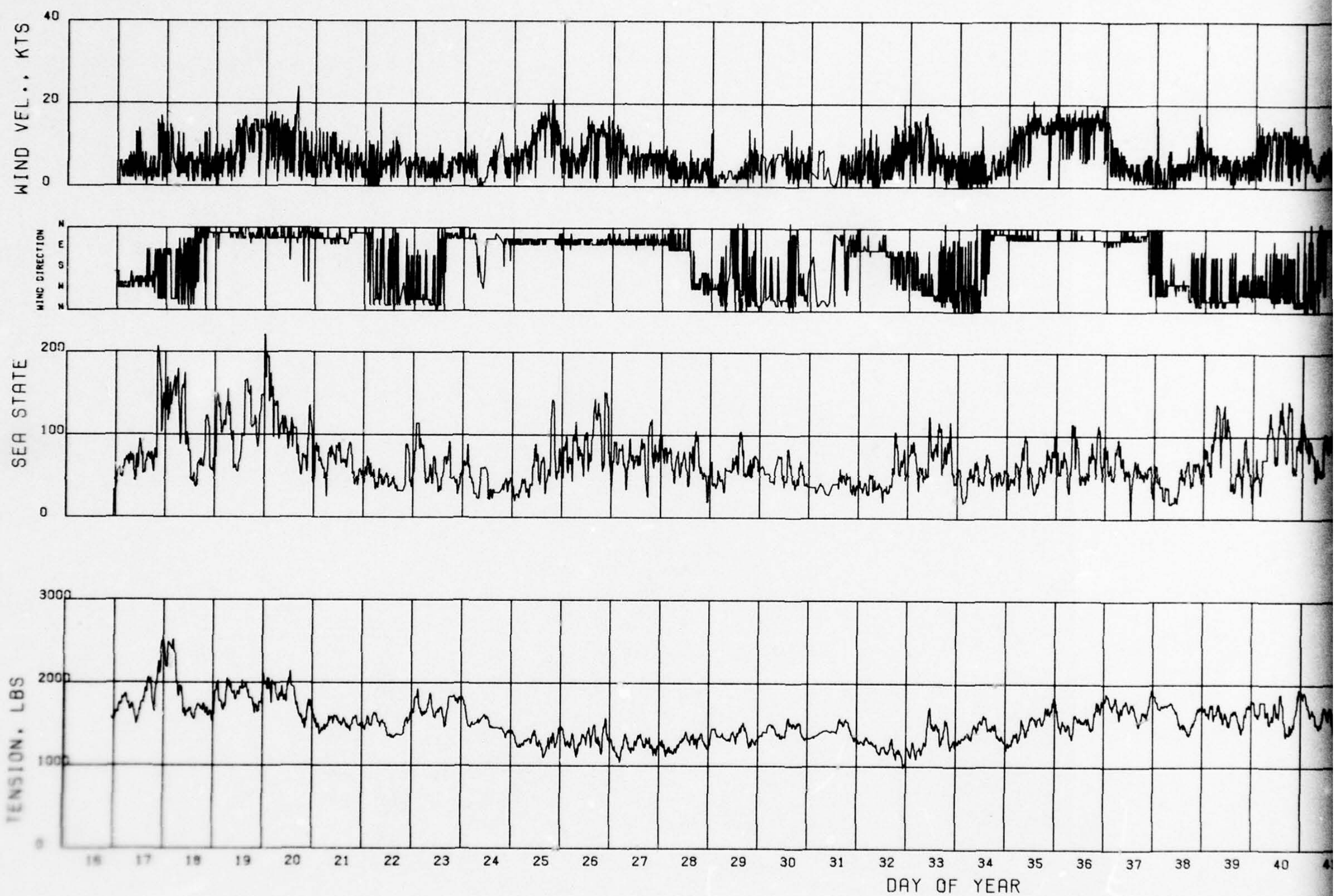
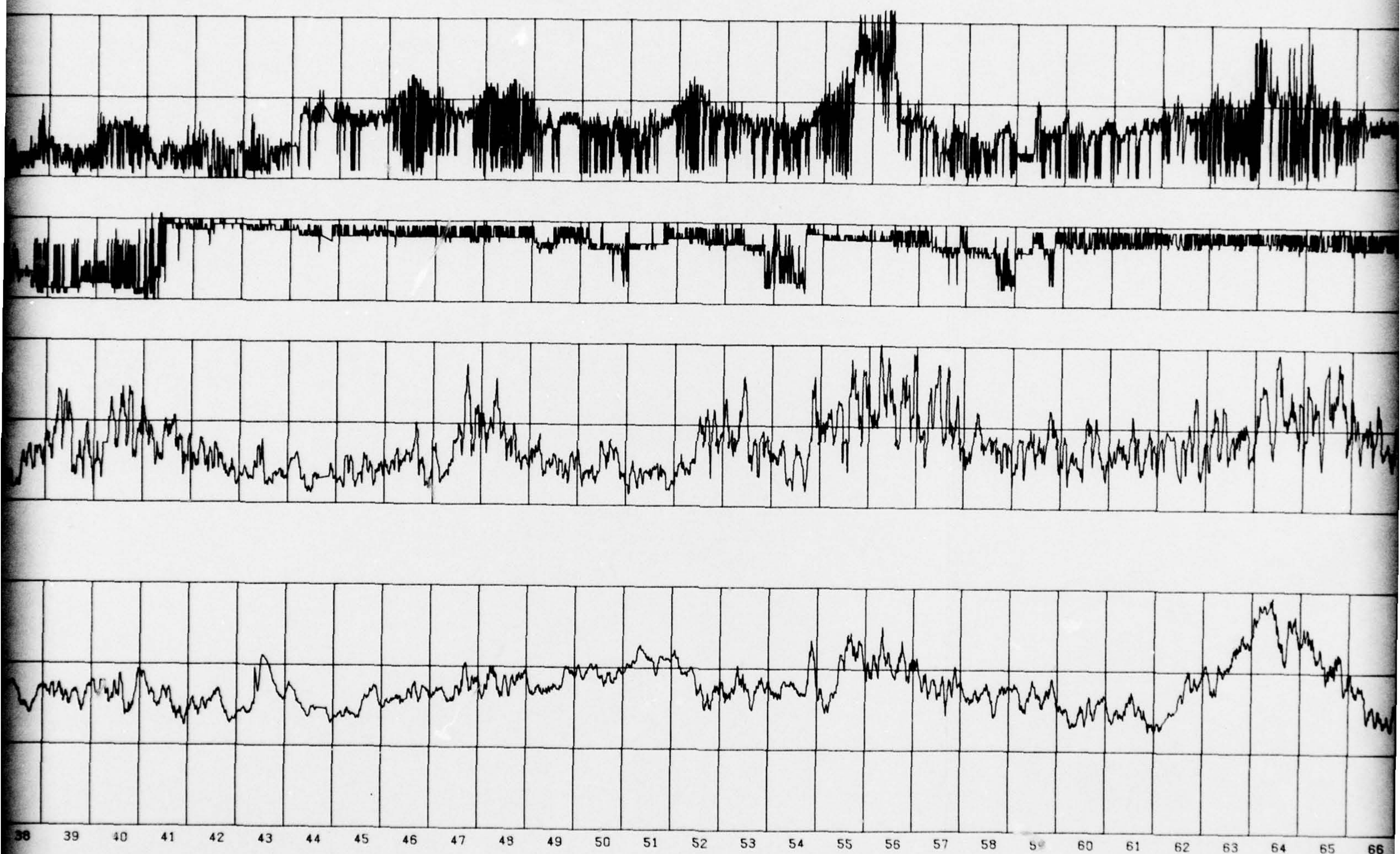


Figure 28. Sound Speed Fluctuations.

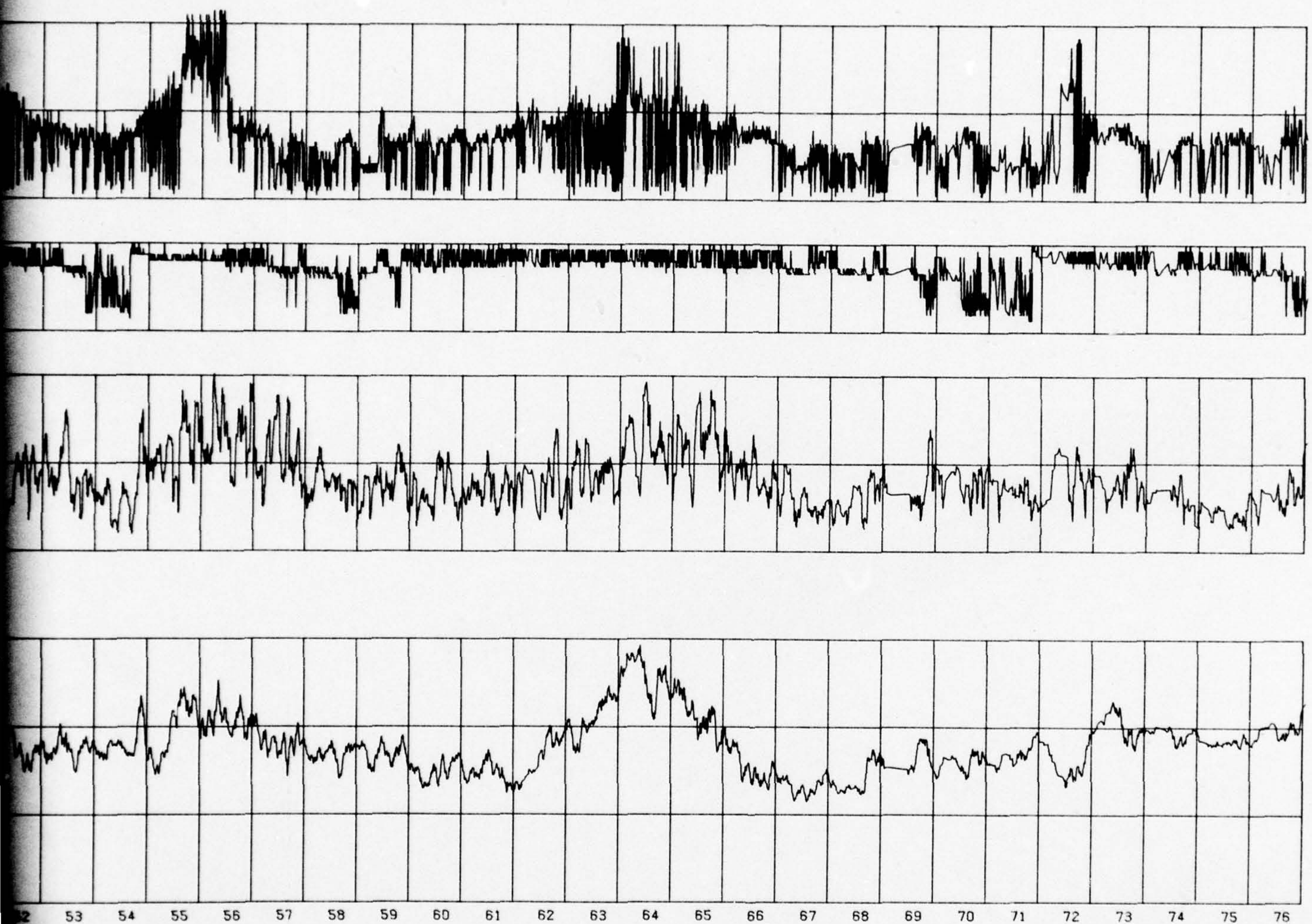


WIND VEL., KTS
40
20
0
WIND DIRECTION
N
E
S
W
N
SEA STATE
200
100
0
TENSION, LBS
3000
2000
1000
0
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
DAY OF YEAR



2

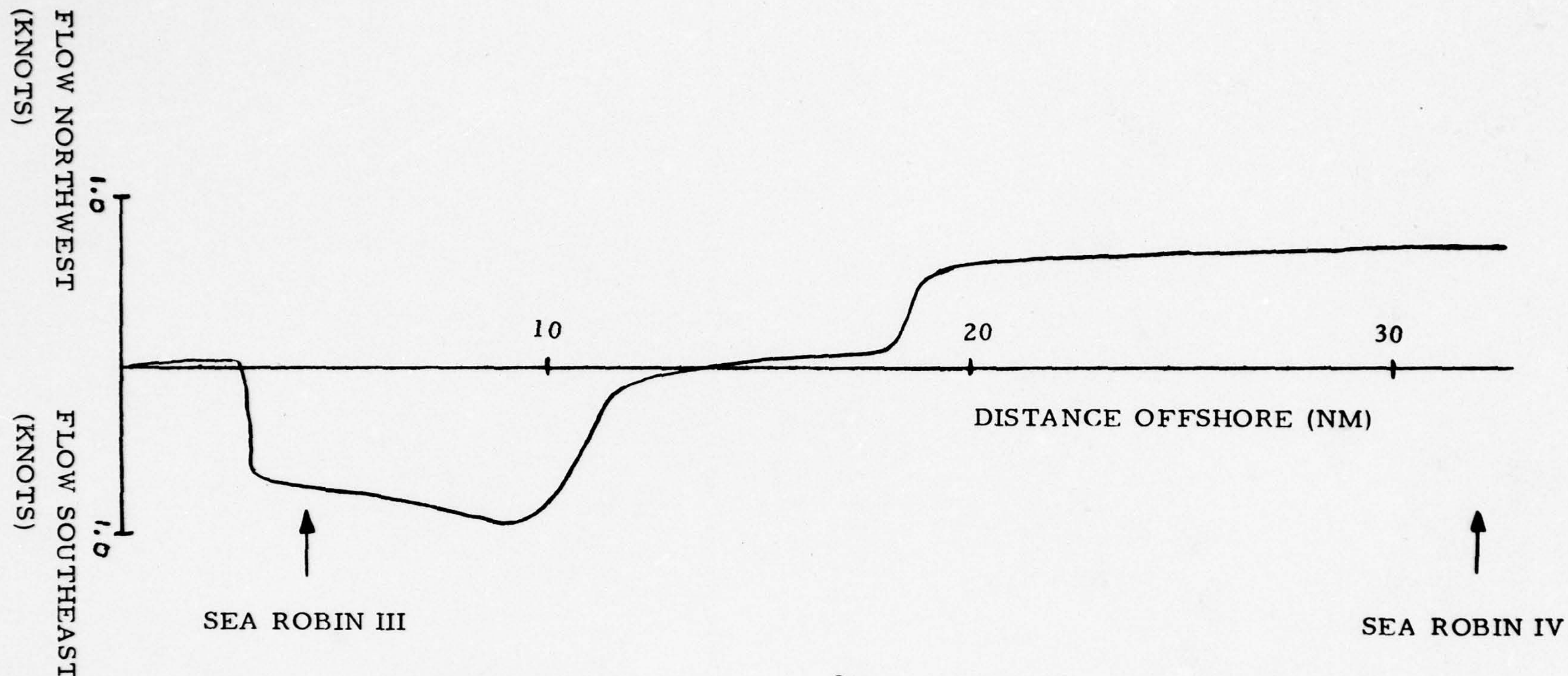
Figure 29. Me



3

13

Figure 29. Meteorological Factors And Buoy Response.



CURRENT NORMAL TO LINE 55°T FROM NAVFAC (ELEUTHERA)

Figure 30 Observed Currents Along 55° Transit.

APPENDIX A

DESCRIPTION OF EQUIPMENT

Pertaining to the Sea Robin Thermistor String Buoy Systems
and Associated Apparatus

CONTENTS

CONTENTS (Continued)

LIST OF FIGURES

TABLE

DRAWING

APPENDIX A

EQUIPMENT DESCRIPTION

A.1. BUOY/MOORING DESIGN

The general arrangement of the Sea Robin Thermistor String Data Buoy and Mooring is shown in Figure A-1. The system is a composite taut, single-stage configuration employing a Sea Robin (modified spar) buoy surface-following float. The mooring comprises a 4000-5000 ft (1250-1500 m) center-strength member thermistor cable for the upper inextensible component and plaited nylon line for the lower elastic member. Two swivels to permit free rotation under load, connecting chain, Danforth contingency anchors and a dead weight clump anchor also are utilized. An acoustic release with a deep water float assembly is located just above the clump anchor. The mooring attaches directly to a frame structure at the bottom of the buoy. A wire-wound, controlled flexure fairlead is joined to the bottom of the frame structure to restrain bending of the mooring cable at the attachment point. When so equipped, the frame also serves to house a nuclear thermoelectric power supply (SNAP-21 RPG).

A.1.1 Approach

This configuration was selected for several reasons. A surface float was used in order to provide on-station access to the instrumentation and telemetry packages. The Sea Robin buoy had demonstrated satisfactory dynamic performance as a surface-following communications platform in two earlier programs and was moderate in size. A composite taut mooring was selected to allow more reliable definition of sensor positions while providing adequate compliance for current loads and buoy motion. Individual mooring components were designed to meet the oceanographic data requirements, and for compatibility with the surface-following characteristics, drag and buoyancy of the Sea Robin hull.

A.1.2 Thermistor String

A.1.2.1 Construction

The upper component of the mooring consists of an integrated thermistor/mooring cable (thermistor string), Figure A-2. The cable is composed of a number of polyethylene-insulated #22 AWG copper conductors helically wound around a torque-balanced, PVC-bedded, 3x19

Amgal* steel center strength member. The rated minimum breaking strength of the structural member is at least four times the maximum design load based upon dynamic tension developed in the cable subjected to conditions of the worst expected storm. The conductors are wrapped with a thermally and electrically insulating binder tape and the entire cable jacketed in 1/8 inch thick high density polyethylene. The jacket is designed to minimize abrasion damage to the cable and also to afford some fish-bite protection. The cable is of "wet" construction; i.e., seawater is free to enter the jacket with electrical isolation being supplied by the polyethylene insulation on the individual conductors. Elements of a cable can be seen in Figure A-3.

The thermistors are molded directly into the individual conductors (one per conductor) to sense temperature at depths ranging from 100m to 1500m. During this process, the outer jacket is opened and, after installation is completed, resealed without the structural member being altered or degraded.

The electrical conductors are terminated at the bottom of the cable in a moulded polyethylene slug. At the upper end, the entire jacketed cable is fed axially through the hollow fairlead at the bottom of the buoy to distribute both conductor and strength member bending, due to buoy pitching motion, over a length of approximately 10 feet. The conductors are separated from the strength member inside the frame structure (RPG cage) of the buoy and routed up along the legs of the frame to penetrate the bottom of the flotation hull through a connector box assembly (see Figure A-4). The upper and lower ends of the wire rope are terminated in galvanized, forged steel, open spelter sockets. Poured metal-filled epoxy secures the rope in the sockets. Attachment to the buoy frame is accomplished through a tensiometer link with safety screw pin connections.

Anti-strumming fairing is applied over the entire length of the thermistor string cable. The fairing consists of polyethylene sheet material cut into ribbons and fastened to the cable with nylon cable ties. Refer to Figure 16 of this report.

A.1.2.2 Thermistor Moulding

Each thermistor is spliced into its respective conductor and is encapsulated to prevent shorting under deepwater pressure. Figure A-5 illustrates the moulded thermistor junction

* U.S. Steel Trademark

whereby a copper plated fiberboard splint is used to provide strain relief for the thermistor leads soldered in series with the conductor wire. An injection moulding process employs a compatible polyethylene resin to fuze with the conductor insulation forming an homogeneous jacket around the splice, Figure A-6.

The injection moulding equipment is shown in Figure A-7. The polyethylene resin is heated to 310°F and injected through a series of ports which are designed to minimize thermistor centering problems. The ends of the mould are cooled (Figure A-8) to 208°F to insure a good bond between the wire insulation and injected plastic.

A.1.2.3 Thermistor String Calibration

In order to calibrate each installed thermistor, a calibration apparatus consisting of a copper block heat sink in thermally insulating polyurethane foam was constructed (Figure A-9). The apparatus splits in half to facilitate positioning the cable with the thermistor to be calibrated properly in place. Temperature of the copper block (and the equilibrated thermistor) is monitored with a platinum resistance thermometer or precalibrated thermistors. The temperature is varied by means of cooling/heating coils soldered to the copper blocks.

A.1.2.4 Thermistor Cable Testing

Tests on completed thermistor cables were performed: (a) To simulate deep water effects on the structure of the cable by subjecting critical cable elements to hydrostatic high pressure in a test chamber (A1)*; (b) To submerge (wet test) a completely assembled cable at above atmospheric pressure in order to uncover and analyze the effects of potential pinhole leaks in conductor insulation, thermistor moulds and/or cable end terminations (A2); and (c) To performance check a representative total system by deploying an abreviated thermistor cable in an ocean environment (Ref. Section 2.3 of this report).

A.1.3 Lower Mooring

A.1.3.1 Assembly

The lower end of the thermistor cable strength member is attached to a contingency-anchor assembly consisting of an in-line series of two "high tensile" Danforth anchors (Figure

*References listed at end of this Appendix

A-1) separated by steel chain leaders. The contingency anchor assembly is provided in the event the nylon lower mooring line fails and the buoy drifts shoreward. The assembly is designed to snag the bottom before coming ashore.

The main component of the lower mooring assembly is the 8-strand Pli-Moor* plaited nylon rope with a breaking strength equivalent to that of the cable strength member. The plaited construction was selected on the basis of its high elasticity, flexibility, and torque-balanced character. The ends of the nylon rope links are terminated in eye splices over extra heavy galvanized steel thimbles.

Two swivels are employed to permit rotation and avoid twist problems during the implant operation while on the moor. Both are PLP** Dynaswivels specifically designed for long-term ocean operation at depth. The upper swivel is located just below the thermistor cable. The lower swivel is located at the bottom of the nylon line which permits anchor rotation during the implantment operation.

The entire assembly is anchored by an iron clump with an acoustic release***, appropriate deep water flotation **** and links of steel chain interposed between the lower swivel and the anchor attachment ring.

A.1.3.2 Nylon Rope Test

To obtain long-term nylon mooring line performance data under simulated ocean environment and loading conditions, several 9/16 inch plaited nylon rope specimens were tested under water for varying periods of up to a year. Rope specimens approximately 4 ft long were loaded cyclically in specially constructed rope test machines. The ends of the rope specimens were terminated in eye-splices over thimbles. Static and cyclic loads were applied by a simple mechanical system incorporating dynamically weighted beams. Rope elongation histories were monitored regularly. The test apparatus is pictured in Figure A-10 with a schematic explanation given in Figure A-11. Pertinent results are displayed in Figures 21 and 22 of this report.

---

*Columbian Rope Company
**Preformed Line Products Company
***AMF Sea-Link Model 242
****Benthos Glass Spheres W/Hard Hat Covers

The static with superimposed dynamic cyclic load levels applied were 880 ± 33 lb and 1700 ± 105 lb in order to simulate the loading conditions for "average" and "storm" seas, respectively, in the Eleuthera area. Cyclic loading frequencies were increased by factors of 1.5 and 3 above the expected surface wave frequencies (6 and 12 second wave periods) to provide "long-term" data at an accelerated rate.

Tests were conducted at both ambient room and near freezing temperatures in order to bound the temperature gradient experienced by an actual deep water mooring.

A.1.3.3 Nylon Line Measurement

Due to the prevalent uncertainty of defining the zero elongation point in a yarn woven rope especially one which employs a highly elastic fiber in a plaited construction, an industry acceptable means for establishing a reference for measurement is necessary. This reference was taken at the point where the line is loaded in tension to 5% of its rated breaking strength and held for at least one hour. A layout of the rig used to measure the nylon mooring lines prior to reeling is shown in Figure A-12.

A.1.4 Buoy Assembly

The original Sea Robin buoy was designed as a satellite communications platform. For stability, a modified spar configuration was employed. To achieve the pitch and heave characteristics required for the communication function, the basic spar was augmented by a conical top section and incorporated a slotted damper section at the bottom. In order to meet the additional requirements of the thermistor string application, the flotation hull was increased in buoyancy, in the case of the Sea Robin III, by extending its cylindrical lower section. The mission of the Sea Robin IV, however, made necessary a complete scale-up of the flotation hull in order to provide the approximately 12,000 lb of buoyancy required.

General arrangement of the resultant buoy configurations are shown in Figure A-13. The flotation hull has a length of 4-1/2 deck diameters (major diameter of upper conical section). The lower cylindrical (spar) section is one half the deck diameter. The RPG cage extends another several feet beneath the flotation hull. Communication antennas, meteorological instruments, a navigation light and a radar reflector, are mounted on a 9 1/2 - 10 ft high superstructure at the top of the buoy. The integrated thermistor string/mooring cable is fed through a 10 ft long flexibe fairlead at the bottom of the buoy and attached directly to the

RPG cage frame. The fairlead is incorporated to distribute cable bending over a sufficient length to prevent bending fatigue failure of the cable elements.

A.1.5 Mooring Analysis

The static loads on the mooring are due primarily to buoy hydrodynamic drag, the weight and drag of various components of the mooring. Additional dynamic loads are introduced by the motion of the buoy on the surface. For this composite taut moor configuration, no significant lateral cable strumming was expected since anti-strumming fairing would be applied down to the depth where resonant frequencies are much lower than the vortex-shedding frequencies encountered at the relative water velocities involved. Further, the elastic properties of the moor component also result in damping longitudinal resonance to the extent that stress-wave propagation and reflection is not a critical factor. The limiting loads are therefore, the quasi-static current-induced loads and the dynamic inertial loads on the mooring due to heave accelerations of the buoy and mooring component masses.

The following two subsections describe the results of the static and dynamic mooring-load analyses, respectively. Details of the analysis techniques are given in Reference A3.

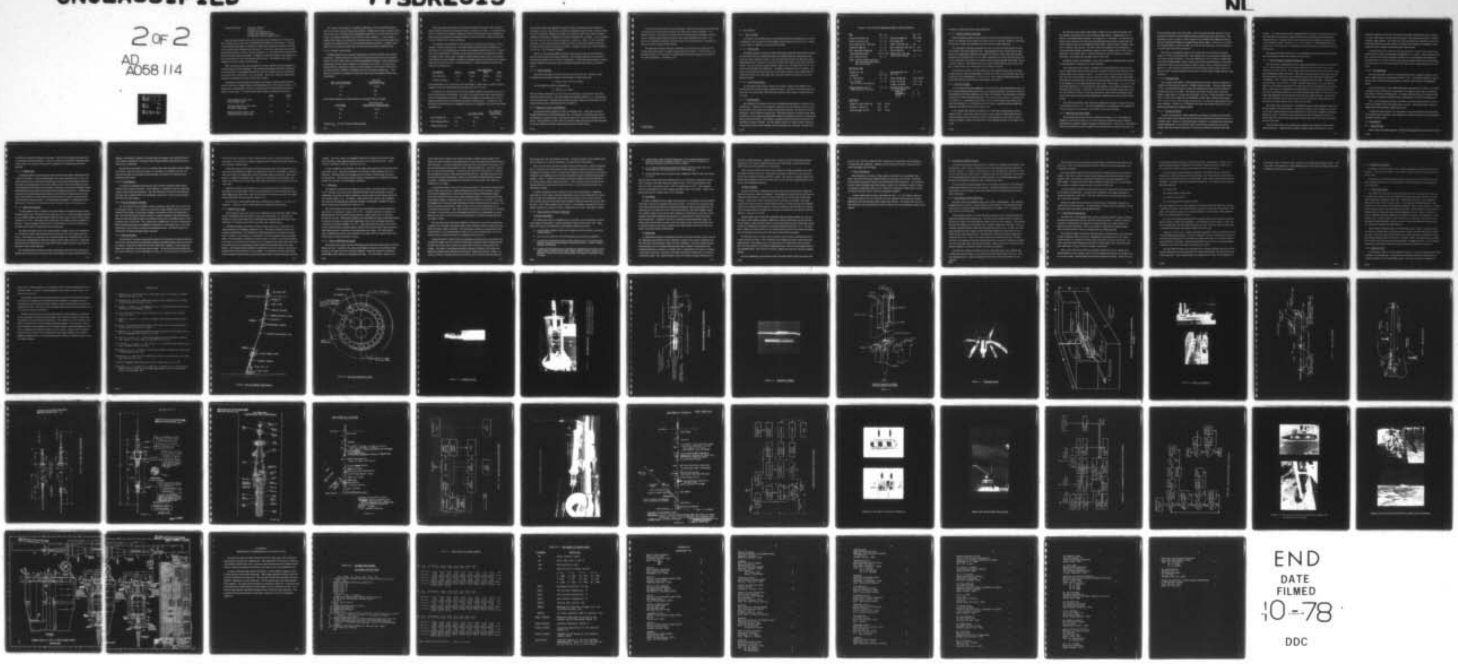
A.1.5.1 Static Loads Analysis

The static mooring loads are caused by the hydrodynamic drag induced by the average currents. Such currents include those due to large scale slowly-varying circulation and wind driven currents in the surface layers. The surface current values are "average values" and do not include the dynamic, periodic orbital water velocity associated with wave motion. Climatalogical wind and wave data were obtained from References A4 and A5. Results indicate the following design conditions:

Most Probable Condition:	20 kt wind, continuous Sea State 4 Average Wave Height 4 feet Average Wave Period 6 seconds Corresponds to fully developed 20 kt sea
Worst Expected Winter Storm:	50 kt wind, 36 hours Sea State - Low 8 Average Wave Height 30 feet Average Wave Period 12 seconds Corresponds to fully developed 40 kt sea

AD-A058 114 GENERAL ELECTRIC CO PHILADELPHIA PA RE-ENTRY AND ENV--ETC F/G 20/1
ENVIRONMENT VARIABILITY IN THE DEEP SOUND CHANNEL.(U)
MAY 77 E J SOFTLEY, M J ENGEL N00014-73-C-0030
UNCLASSIFIED 77SDR2315 NL

2 OF 2
AD
A058 114



END
DATE
FILMED
10-78
DDC

Potential Hurricane: 80 kt wind, 24 hours
Sea State - Low 9
Average Wave Height 50 feet
Average Wave Period 14 seconds
Corresponds to fully developed 50 kt sea

Fully developed surface current and mixing layer depth predictions over the range of wind velocities from 0-80 kts were obtained using the methods of Reference A6. The total current variation with depth was obtained by adding these wind driven currents to the large scale current profiles obtained from Reference A7. Conservative estimates were obtained by aligning all current vectors in the same direction; i.e., the rotation of the current vector due to the Eckman effect was ignored. In addition, for analysis purposes, the currents have been increased by 50% over the measured value (no wind). The design current profiles obtained are shown in Figure 6 of this report.

Static mooring loads were then calculated for various candidate mooring configurations over this range of current conditions. The computerized technique described in Reference A3 was employed. Load elongation data for the nylon were obtained from the manufacturer and in-house tests (see Section A.1.3.2 preceding). The nylon is measured under tension and data were obtained for one hour and one year periods.

Calculations were performed for the design moor depths varying from 6000-8000 feet and to 16,500 feet to evaluate effects of implant depth errors for two ranges of depths. For example, for a design depth of 15,500 ft, results for steel and nylon tension are given in Figure 7 of this report. The safety factors at the design sea conditions indicated are:

	Steel	Nylon
Most probable sea (cont. 20 kt wind) "average" loads	5.5	7.4
Worst expected storm (36 hr, 50 kt wind) Max. design loads	4.0	4.8
Potential hurricane (24 hrs, 80 kt wind) Exceed max. design loads	3.0	3.6

The mooring was designed to maintain the safety factor at four in both the nylon and steel for the worst expected winter storm condition. Although the hurricane condition exceeds these design loads, the tension results indicate that safety factors are still sufficiently high to give a reasonable probability of moor survival in that contingency. In this example, a positive 500 ft depth error reduces the nylon safety factor to 4.0 at the worst expected storm condition and to approximately 3.2 for the potential hurricane condition. A negative 500 ft depth error, increases the safety factor by about 15% over the above tabulated values.

A.1.5.2 Dynamic Loads Analysis

Simplified analyses were employed to determine the dynamic stresses in the mooring components. Results indicate that, because of the high sound speed in the steel structural member of the thermistor cable, the resonant longitudinal frequencies of this component are much greater than the driving frequencies of the surface wave motion. The cable can be approximated as a rigid body, in heave, so that the dynamic loads are due to the inertia of the cable with some additional contribution from the nylon spring constant (K_{ny}). For a cable mass of 2800 lb, the dynamic inertial loads in the cable are dependent on buoy heave accelerations:

Buoy Heave Acceleration	Steel Cable Cyclic Inertial Load
0.1 g	275 lb
0.2	550
0.3	825

Cyclic tension changes due to nylon stretch are a function of the wave height:

Wave Height	Steel Cable Load Increment Due to Nylon Stretch*
20 ft	± 30 lb
30	± 45
50	± 75

* Based on K_{ny} = 3. lb/ft @ 25% of breaking strength

The nylon-stretch (increments are normally 180 degrees out of phase with the inertial loads and tend to reduce the total cyclical (dynamic) loading on the cable. In a statistical sea, however, maximum accelerations might occur at other than minimum-stretch conditions so that a conservative estimate of maximum dynamic loads in the cable is obtained by ignoring the heave-induced nylon stretch variations.

An evaluation of the dynamics of a Sea Robin buoy was performed employing a GE Buoy Dynamic Computer Program (A8). The pitch and heave results of these calculations for sinusoidal waves corresponding to the average wave height and period of the "most probable" and "worst expected storm" conditions and the spectral response characteristics are shown in Figures 8 and 9 of this report. Evaluation of buoy motions in these cases, and estimates of the effects of a more realistic, statistical sea surface indicate that maximum buoy accelerations will not exceed 0.2-0.3 g. For the Sea Robin IV, maximum dynamic tensions in the cable were estimated to be:

Sea Condition	Max. g	Steel Cable Loads Dynamic	Static	Total
Worst Expected	0.3	750 lb	3900 lb	4600 lb
Potential Hurricane	0.3	750	5100	5850

and proportionately less, for the case of the Sea Robin III. Safety factors based on ultimate strength for the steel cable with these total loads vary from 3.2 to 2.5.

An analysis was also performed to evaluate potential problems with dynamic stresses in the nylon component of the mooring. The cyclic wave-induced nylon stretch loads discussed above are also present in the nylon. The additional possibility of resonant stress wave propagation along the nylon was evaluated as described in Reference A3. To illustrate, if the first order resonant periods for longitudinal stress-wave propagation in the nylon at the design conditions are:

		Ave. Wave Period	Min. Significant Wave Period
Most Probable Sea	3.1 sec.	6 sec.	3 sec.
Worst Expected Storm	3.0	12	7
Potential Hurricane	2.8	14	8

then results indicate that longitudinal resonance of the nylon should present no problem at the higher sea states since the wave periods are significantly longer than the resonance period. At the 20 kt condition, although the average wave period is a factor of two off the resonance condition, some energy is distributed at shorter wavelengths near resonance. It was presumed that, since the buoy motion at these frequencies is small; e.g., about ± 1.5 ft at buoy heave resonance, viscous drag and internal friction in the nylon will provide sufficient damping to prevent excessive dynamic stresses in the nylon. In addition, static loads at these conditions are low; i.e., 12% of breaking strengths.

Further, it was estimated that the maximum tension in the nylon may be increased by dynamic loads of 150 lb at the storm conditions. The resulting safety factors for the 50 kt and hurricane conditions are 4.5 and 3.3 respectively. At the 20 kt design condition, dynamic stresses would have to increase loads by 60 percent before the safety factor is reduced to below 5.

A.1.5.3 Anchor Criteria

The loads on the anchor are equal to the tension in the nylon line. Maximum values computed for the hurricane condition at the Sea Robin IV design depth were:

$$T = 4200 \text{ lb, Angle} = 30^{\circ} \text{ from vertical}$$

The horizontal and vertical components are:

$$T_V = 3600 \text{ lb}, \; T_H = 2100 \text{ lb}$$

Since the bottom composition in the moor area was uncertain, a clump anchor rather than embedment type was chosen. The clump weight was specified at 8000 lb, i.e., approximately twice the anchor load. Computed loads and selected anchor weight for the Sea Robin III were approximately half those determined for the Sea Robin IV.

A.1.6 Materials Corrosion Considerations

The basic Sea Robin structure was 6061-T6 aluminum alloy. Plain steel components included the RPG frame and the tensiometer link. The fairlead, the mooring cable with its end fittings were galvanized steel. All fasteners (bolts, etc.) were either stainless steel or monel. When applicable, the RPG SNAP-21 pressure casing was Berylco 165 and held rigidly by phenolic laminate and rubber support pads attached to the cage frame.

In order to minimize galvanic corrosion problems, critically dissimilar metal components were galvanically isolated from one another with epoxy glass laminate interfaces. The specific RPG unit was selected for its high value of electrical leakage resistance in order to isolate conduction paths between the Berylco case and the aluminum buoy parts. Also, several zinc sacrificial anodes were attached to buoy and mooring hardware components as a back-up protection against galvanic activity.

The underwater aluminum and steel components were painted with an organo-tin anti-fouling marine paint system* to inhibit marine growth and corrosion. Above the water, the aluminum surfaces were alodined and/or painted with epoxy based coatings for protection in the marine atmosphere. See Figure A-14.

* Porter 305AF

A.2 SEA ROBIN III

A.2.1 Buoy Assembly

To reiterate, the Sea Robin III buoy was the final evolvement resulting from a series of modifications to the original Sea Robin-Satellite Communications Buoy (A9 & A10). Figure A-13 and Table A-I illustrate and characterize the buoy.

A.2.1.1 Flotation Hull

The flotation hull was comprised of three bolt together aluminum alloy tank-like sections. The conical and the lower cylindrical sections were double hulled per requirement of the earlier Sea Robin application (Figure A-15), the interspaces having been utilized for structural flotation foam in the upper conical section and for fuel storage in the lower cylindrical section. The seven foot long central cylinder, Figure A-13, was added to the flotation hull as part of the Sea Robin III modification. In addition to adding buoyancy and stability, this section was projected to house main power source battery packs in correct anticipation (as it turned out) of the GFE radioisotope power generator (RPG) being deleted from the Sea Robin III mission.

A.2.1.2 Lower Buoy Structure

The Sea Robin dynamic damper section was retained, reinforced and adapted to the house the RPG frame and mooring connection structure. The frame constructed from structural steel was appropriately isolated from the aluminum alloy damper to impede galvanic corrosion.

A.2.1.3 Superstructure

The original buoy's antenna tower was not salvagable having suffered irreparable field modifications. Therefore it was completely replaced as were the antennae in order to meet the particular transmission and reception requirements imposed by the Sea Robin III operational plan. The Sea Robin III antenna tower, fabricated primarily of aluminum alloy tubing in the form of a four-sided pyramidal ladder, offered a mounting base some 9-1/2 feet above the top of the buoy hull for a VHF antenna, navigation light and such other instruments and apparatus as might be included. The VHF antenna made up of a sturdy coaxial centerpost surrounded by a fully rimmed radially spoked ground plane was especially structured to be

TABLE A-I SEA ROBIN/THERMISTOR STRING CHARACTERISTICS

Buoy	III	IV		III	IV
Maximum Diameter (ft)	4.1	5.4	Structure Weight (lb)	1750	2900
Minimum Diameter (ft)	2.0	2.5	RPG Weight (lb)	-	650
Hull Length (ft) incl. RPG cage	22	28	Battery Pack Wgt. (lb)	400	-
Fairlead Length (ft)	10	10	Instr./Telemetry Wgt. (lb)	50	200
Max. Submerged Length (ft)	32	38	Total Weight (lb)	2200	3750
Total Displacement (lb)	6100	11,700	Distance from Calm Sea Water Line to CM (ft)	6.0	7.2
Max. Drag Area (ft^2)	44	75			
Mat'l: Al 6061-T6 Hull & Sprstrctr	-	-			
Stl C1020 (RPG) Cage/Frame	-	-			
Stl 11L17 Fairlead	-	-			
Thermistor Cable					
Outside Dia. (in)	3/4	1	Jacket Thickness (in) (Hi-ρ PE)	1/8	1/8
Length (ft)	4100	4900			
No. Thermistors	12	18	Break Strength (lb)	8000	14,800
No. Conductors (No. 22 AWG, PE insulation)	14	24	Weight, dry (lb/ft)	0.28	0.54
			Weight, wet (lb/ft)	0.08	0.23
Strength Member Size (in) (USS Amgal 3x19 wire rope)	1/4	3/8	Anti-Strumming Fairing (6 mil PE ribbon)	-	-
			Width (in)	3	3
			Standoff (in)	5	6
			No./ft	3	3
Nylon Rope					
Length, dry unstretched (ft)	3400	10,200			
Diameter, plaited (in)	9/16	3/4			
Break Strength, dry (lb)	8000	14,200			

resistant to inadvertent damage during deployment.

A.2.1.4 Internal Equipment Packaging

Three (3) tubular peripheral rails extending downward from the main hatch to near the bottom of the flotation hull provided the principal means for insertion, alignment, positioning and securing of all the pre-packaged electronic and power supply equipment.

Four (4) battery packs the components of which were foam potted into plastic canisters were sized to slide freely within the rails. Notched flanges at one end provided polarizing guides and permitted the trailing of a retrieval line and power cable. Each pack consisted of fourteen (14) Eveready #561, 15 volt, alkali rechargeable dry cells wired with appropriate circuit components to furnish the line voltage needed to operate specific electrically powered on-board equipment. The battery packs were positioned deep within the buoy cavity so that their weight in that location would enhance the stability of the buoy.

The electronics module, similarly designed to slide within the guide rails, presented circular platforms with connecting plates as surfaces on which to mount the data processing, monitoring and transmitting gear. In this instance, this relatively lightweight package was located near the buoy's top for ease of accessibility and service.

A.2.2 Mooring Assembly

The Sea Robin III mooring configuration was derived from data obtained from surveys of the proposed implantment site made under or in conjunction with this contractual activity and from published information relating to prevailing meteorological and oceanographic conditions including water depth and bottom topography. The data were used to generate a mooring analysis (Section A.1.5 preceding) which together with the characteristics determined for the nylon rope (Section A.1.3.2 preceding) served to produce a specific mooring configuration within the constraints of the mission (Figure A-16).

Thus, with the site selected for deployment of a thermistor string having a nominal depth of 7000 ft, a 1250 meter (4100 ft) long thermistor cable was constructed such that 12 active thermistors spaced 100m apart down the cable beginning at 150m from the surface would be available to monitor the temperature of the stratified currents in that region of the ocean.

The Sea Robin III thermistor cable (Refer to Table A-I) was joined structurally to the buoy through a tensiometer link, which monitored cable tension. Bending loads were relieved by a controlled flexture fairlead. See Section A.3.1.2 following. The electrical conductors were connected to the buoy data processing electronics through a single multi-pin marine bulkhead connector assembled and sealed within a special pressure resistant, waterproof, conductor splice housing. The lower ends of the conductor wires terminated in a common junction moulded in polyethylene while the center strength member at this end was fastened to a PLP marine swivel. Just above the swivel a General Oceanics recording inclinometer was clamped to the strength member of the cable.

Beneath the swivel was suspended a series of two Danforth embedment anchors shackled to and separated by 4 ft lengths of 5/8 inch steel chain.

The compliant mooring member consisting of 9/16 inch plaited nylon rope measuring 1030 m (3080 ft under 400 lb tension) with ends eye spliced over heavy duty galvanized steel thimbles followed the contigency anchors. A second marine swivel joined the nylon to the lower mooring assembly which comprised a model 242 AMF Acoustic Release with Benthos glass sphere deepwater floats in protective individual polyethylene "hard hats" linked between 15 foot lengths of 3/8 inch high strength alloy steel chain. At this point, a "vee" of 1/2 inch steel chain separated by a 5/8 inch diameter steel spreader bar provided for attachment of the deployment crown line. And finally, a 5000 lb cast iron deadweight clump anchor with a four-part bridle of 10 ft long 1/2 inch chain shackled to a third swivel (of standard quality since it only needed to function during deployment) completed the mooring for the Sea Robin III buoy.

The crown line assembly, also employed to implant the Sea Robin IV buoy and mooring, is described in Section A.3.2. The principal difference in its application to the deployment of the Sea Robin III was the deletion of the elastic (nylon rope) component.

A.2.3 Electronics and Power Supply

The Sea Robin III electronic system is diagramed in Figure A-17. The system was designed to operate for at least one year under worst case timing and control conditions utilizing power supplied by alkaline-manganese dioxide batteries. Eveready No. 561 batteries were used exclusively but were arranged in three separate power systems for operation of:

(1) the navigation light; (2) the transmitter, receiver/command decoder and timer; and (3) the dc/dc converters to operate signal conditioning and data acquisition electronics. This separation of power was done in order to optimize the available power utilization since the various subsystems had different acceptable input voltage ranges: 15 volts to 10.5 volts for the navigation light; 30 volts to as little as 20 volts for the transmitter, receiver and timer, and 30-24 volts for the dc/dc converters.

The system was designed to acquire and transmit data on command from the shore station via a VHF communication link. Data requests were to be sent twelve minutes after each successful data acquisition. In the event that the buoy was to receive no recognizable valid request within thirteen minutes, the buoy on-board clock would initiate a transmission and then turn off the command receiver for eleven minutes. Also, provision was made to allow for as many as five data requests to be honored during each two minute receiver-on period in order to facilitate adequate data transfer even under adverse weather and sea-state conditions.

A. 2. 3. 1 Navigation Light

The navigation light utilized a NE555 integrated circuit timer, which was triggered by a cadmium-selenide photocell whenever a twilight condition existed. The timer would enable a dc/dc converter flash lamp power supply and unijunction transistor timer for about five seconds out of every 25 seconds. The unijunction transistor timing was set to give five flashes, spaced about 0.8 seconds apart during this "on" time. Energy per flash was nominally 0.5 joule into an Amglo type U-35B flashtube located within a lenticular lens shaped glass housing at the top of the navigation light package. The light was mounted atop the antenna tower structure. Fourteen No. 561 batteries were used in the battery pack to give an estimated nominal life time of eighteen months.

A. 2. 3. 2 Timing and Control

On-board timing utilized a NE555 integrated circuit timer to activate the command decoder and receiver eleven minutes after the end of the previous data transmission period via a latching relay. Receipt of a valid data request resulted in a 1.86 second data transmission and the triggering of a 27 second timer which reset the eleven minute timer on time-out. Further valid data requests during this 27 second period resulted in additional data trans-

missions. If no data requests had been validated within two minutes of receiver turn-on the data acquisition and transmitter circuits would have been activated and data transmitted continuously for 6.6 seconds in order to have maximized the probability of satisfactory receipt at the shore station even under severe sea-state conditions. Self-activated data transmission also would trigger the 27 second timer to reset the master eleven minute timer and latching relay.

The timing and control circuit drew 11.5 milliamperes average current from the power pack which amounts to about 100 ampere-hours in one year.

A.2.3.3 Data Acquisition and Signal Conditioning

The data encoder multiplexed thirty-one analog input channels into a twelve bit A/D converter, added an odd parity bit (if necessary) and three word sync bits for use in error checking at the shore station. The resultant sixteen bit digital data words were put into a split phase (Manchester) pulse code format. Each frame of data consisted of these thirty-one data words preceded by a frame sync word of sixteen bits (for use by the shore station data decommutator). For 1.4 seconds after power was applied to the transmitter, signal processor and data encoder, the 5 kilohertz crystal-controlled clock frequency was transmitted to allow the shore station decommutator to acquire phase lock and the signal processor to stabilize. This warm-up was followed by the transmission of four complete frames of data. The frame word format would have co-ordinated with that of Sea Robin IV in such a way as to easily allow identification of the data source by the shore station computer. Word 32 was frame sync for SR-III, zero for SR-IV; word 33 was zero for SR-III, full-scale for SR-IV; and word 48 was full-scale for SR-III, frame sync for SR-IV.

Thermistor signal conditioning was accomplished using a single integrated circuit operational amplifier for each thermistor. Thermistor resistance was nominally 15,000 ohms at 25°C and a current of about ten microamperes was used to assure negligible self-heating (less than 0.01°C). Circuit gain of ten assured that a range of temperature from 0°C to greater than 35°C could be tolerated without exceeding full-scale data encoder input levels of zero to five volts.

The first twelve data words contained the amplified output voltage from the mooring cable thermistors. Additional data included the supply voltage for thermistor current,

thermistor unbalance current (see the discussion of signal conditioning for SR-IV, Section A.3.4.2), cable tension, surface water temperature, buoy internal temperature, reference amplifier output voltage (to check long-term drift of the thermistor amplifiers), thermistor termination voltage (to permit computer correction of the temperature calculation), power supply and battery voltages and buoy leak check measurements.

The digital data were clocked out of the data encoder at a 5 kHz bit rate so that a complete frame of 32 words was transmitted in slightly over 0.1 second. Power required by the data acquisition and signal conditioning circuitry was a nominal nineteen watts during its activation; however, because of the low duty cycle its average battery drain was nominally 15 ampere-hours per year and 75 ampere-hours worst-case (5 transmissions every 12 minutes).

A.2.3.4 Communications

The VHF transmitter used was a Teledyne Model TR-11A, designed to deliver a nominal 2.5 watts of RF power output at 234.0 MHz ± 0.01%. Frequency modulation of the output was used to maximize data transmission reliability at the 5 kilohertz modulating frequency.

The command receiver was an RSE Model 2623C operating at 251.5 MHz ± 0.005% with a sensitivity of no more than five microvolts for 6 db signal-to-noise ratio and requiring only about 1.4 watts of operating power. Its output coupled directly into a companion RSE Model 1805W six-channel command decoder requiring about 0.55 watts of standby power.

Thus, the RF equipment would have consumed a nominal 63 ampere-hours per year or a worst case battery drain of 130 ampere hours per year. This and the timer could have operated for at least fourteen months (worst case).

A single broad band quarter-wave stub antenna was used for both the data transmitter and command receiver/decoder, with a diplexer for isolation of the two to avoid the need for an antenna switching relay.

A.3 SEA ROBIN IV

A.3.1 Buoy Assembly

Refer to Buoy Assembly drawing No. TSSR-E2000 (appended herein) and the several sub-

assembly and component drawings as necessary. Table A-I lists pertinent characteristics in comparison with the Sea Robin III. Figure A-18 shows the Sea Robin IV assembled undergoing systems and continuity testing prior to transport to its embarkation point and deployment.

A. 3. 1. 1 Flotation Hull

The flotation hull is a one piece aluminum alloy weldment whose walls are fabricated of 5/16 inch and 1/4 inch plate. An 8 inch pipe through the axis provides a tunnel for power, sensor and signal cabling to connect with the power conditioning, instrumentation and telemetry equipment housed in removable canisters in the top section of the buoy hull. The entire hull below the upper cylindrical section between the outer wall and the central pipe is closed cell foamed with low density polyurethane for improved structural rigidity and anti-sinking characteristics. A double sealed connector box assembly leading to the wiring harness tunnel fits into a flanged protrusion at the bottom of the hull and serves to distribute incoming wires and the main power cable through five marine connector fitting assemblies. Provisional tubing and fittings are installed which would allow for the incorporation of a propane fueled power generator in place of the nuclear unit.

A. 3. 1. 2 Lower Buoy Structure

The RPG support frame is attached to the bottom flange of the flotation hull and extends beneath the hull 4.5 ft. The SNAP-21 power generator pressure casing was rigidly supported by non-metallic isolation pads (phenolic laminate and rubber) which are built into the welded structural steel frame. The upper section of the cage is removable to permit installation of the RPG. A thick rectangular steel bar with a 3/4 inch diameter pin hole is welded across the bottom of the frame for attachment of the mooring cable.

The upper termination socket of the mooring cable's strength member was attached to a 3/4 inch diameter clevis-ended steel tensiometer link which was in turn linked to the RPG frame. These joints were subjected only to tensile loadings since all bending loads were removed by the controlled flexure fairlead arrangement at the bottom of the buoy. Both cable/link and link/frame attachments were made with 3/4 inch minimum diameter monel pins and retained by cotter-keyed safety nuts.

The controlled flexure fairlead was bolted to the bottom of the RPG frame section independent of the mooring cable to minimize cable bending fatigue problems associated with buoy

pitching. The fairlead, comprised a complex steel wire wrapped, semi-conical structure over a hollow urethane tube, 10 ft long overall, through which the cable entered the bottom of the buoy for attachment.

The fairlead was designed (A11) for low bending stress along its length so that its stiffness varied from a high value at the buoy bottom, to essentially zero stiffness at its free end. And since the cable was permitted to slide internally, the fairlead was subjected only to bending and shear loads.

A.3.1.3 Superstructure

A 10 foot mast extending upward from the deck of the buoy supported approximately another 20 feet of tuned HF antenna, a radar reflector, a navigation beacon and, optionally, a group of meteorological instruments. The mast constructed of nominal 4-inch aluminum alloy pipe with an integral ladder was structurally reinforced by evenly tensioned stainless steel wire rope cable rigging.

A.3.1.4 Internal Equipment Packaging

Four (4) cylindrical instrumentation canisters (aluminum alloy) offer some 20 cubic feet total stowage capacity. The canisters are accessed by double-walled hatchways to facilitate unexposed intercanister communication cabling, operational servicing and replacement at sea. The lower half of each canister is housed in a pocket moulded into the internal foamed structure of the buoy hull; the upper end is flange mounted to the deck bulkhead about 5 inches beneath its outer access hatch. The canisters were outfitted with: (1) power conditioning and data processing equipment, (2) navigational and telemetry communications gear, (3) an independent power source (battery pack) for the navigational beacon. The fourth canister was reserved for acoustical hydrophone data processing.

A.3.2 Mooring Assembly

The Sea Robin IV mooring composition like that for the Sea Robin III was determined from site surveys, and the surface and subsurface conditions generally existing in the area selected for implant. Unlike the Sea Robin III, this buoy system was to situate in a region where the bottom was mainly flat and more than twice the depth. The Sea Robin III having significantly less reserve buoyancy, a shorter and lighter mooring was to be deployed over a sloped bottom.

This provided the rationale for a finite length mooring (Figure A-16) which could be targeted close to the exact site by carefully trawling the buoy and mooring until the sloped contour produced a matching depth.

On the other hand, the Sea Robin IV carried aboard the launch vessel provision for varying the mooring length during deployment through the insertion of individually sized links of nylon mooring line as required after a final fix on bottom depth was acquired. With reserve buoyancy available in the flotation hull, a depth error of 100 ft (30m) was tolerable. The anchor was released to drop freely to the bottom after being lowered on the crown line to 80% of the depth.

Referring to Figure A-19 and Table A-I, it is seen that except for the difference just described, the sizes and lengths of the several component parts and the clump ancher being of the hedgehog type rather than a slab, the Sea Robin IV mooring make-up was very similar to that described for the Sea Robin III in Section A.2.2.

The crown line, used to deploy both buoys, is defined also in Figures A-16 and A-19 respectively. A Model 322 AMF Acoustic Release was employed in this assembly.

A.3.3 Nuclear Power Supply

The Sea Robin IV main power source was a radioisotopic power generator (RPG), Model SNAP-21 furnished by the Naval Nuclear Power Unit, Fort Belvoir, Va. The RPG was mounted in a special cage built into the structural frame extending downward from the buoy hull where it is exposed to the seawater environment for cooling purposes.

A detailed description of the SNAP-21 RPG is found in Reference A12 and other information pertinent to its handling, in Reference A13. The design is based on extreme conservatism and durability. The radioisotope strontiumtitanate fuel is enclosed in a capsule made of Hastelloy-C; this capsule is surrounded by a two-piece depleted uranium biological shield. The fuel capsule is designed to contain the fuel in a seawater environment at depths of as much as 20,000 feet for more than 300 years at which time the activity of the fuel would be less than one Curie thus assuring the fuel's containment during the decay of its radioactivity. The biological shield reduced the radiation dose rate at the surface of the RPG to a small harmless amount of gamma (x-ray) radiation. No radioactive material could escape from the generator surface because of the conservative double-containment design of the fuel

capsules. The entire system was completely enclosed in a Berylco-165 pressure vessel which sealed the system against seawater pressure, up to 10,000 psi if need be. Hence complete radiological safety was assured at all times.

A power conditioner converted the 4.96 vdc output of the generator to the 24 volts needed by the buoy system. The power conditioner also served as voltage regulator and as a no-load shunt. Electrical leads were brought out of the pressure vessel through a pressure proof penetrator. The electrical output receptacle of the generator was fitted with the proper Berylco-165 connector to prevent galvanic corrosion.

A.3.4 Electronics

The electronics onboard the Sea Robin IV buoy is shown in the block diagram of Figure A-20. Basically, the system can be subdivided into three major subsystems: (1) power conditioning and control; (2) signal conditioning, data acquisition and formatting; and (3) data transmission (Figure A-21). In addition, a separate part of the system is the completely self-contained and independently controlled navigation warning light, virtually the same as that described for the Sea Robin III in Section A.2.3.

All of the electronics subsystems utilized commercial grade components designed for operation over a temperature range of $0^{o}C$ to $70^{o}C$. Particular attention was given to isolating signal grounds from power grounds except at a single point in order to eliminate ground loop currents. Differential amplifiers were used within the signal-conditioning package to minimize the effect of common mode interference with a goal of providing temperature measurement resolution capability of $0.05^{o}C$. Silica gel dessicant packages were provided in each of the electronics canisters and the canisters were sealed using O-rings and hermetically sealed electrical connectors for the signal and power cabling. All cabling utilized rubber insulated wires and the cable connectors were potted with RTV silicone rubber to eliminate exposed electrical contacts or wiring.

A.3.4.1 Power Conditioning and Control

The primary power source was the radioisotope power generator (RPG) rated at ten watts, twenty-four volts. Therefore, the system was designed to consume no more than ten watts average power under worst case operating conditions. Peak power demand is supplied by NiCad battery packs which were recharged by the RPG. A 12 volt battery, made up of ten

series-connected 2.2 ampere-hour rated NiCad cells, provided continuous power to the timing and control circuitry and intermittent power to the Loran data latch and high frequency (HF) transceiver. Nominal average power drain from the 12 volt battery for the twelve minute data transmission rate was about 2.3 watts with the largest part, 1.625 watts, going to the 7.5 second data transmission. Worst case power drain was an average of 2.5 watts for the self-triggered fourteen minute data transmission interval. Peak power drain was about 150 watts during data transmission, but this was well within the pulsed discharge rating of the battery. Charging of this battery from the RPG was at an average rate of about 225 milliamperes (5.4 watts).

A second NiCad battery made up of 22 series-connected 1.5 ampere-hour cells provided power for the Loran receiver, antenna switching relay and the dc/dc converters, which in turn provided regulated power to the data acquisition and signal conditioning subsystem. The Loran consumed 30 watts of power when operating; therefore, it was turned on for only long enough to acquire a position fix (under worst case conditions, 52 seconds). The resultant digital data were stored in logic data latches until buoy data transmission occurred. The dc/dc converters required about 21 watts of power, but were only energized for the 7.5 second transmission period. Thus, the nominal average power drawn from the 28 volt battery was about 2.4 watts while an average charging current of about 110 milliamperes was supplied from the RPG via a dc/dc converter based charging circuit whose average input power was about 4.5 watts.

The only other power requirement supplied by the RPG was to the two axis inclinometer installed on the mooring to provide thermistor cable inclination so that corrected thermistor depth information could be calculated. The inclinometer package was powered (during data transmission) by a 12 volt NiCad battery made up of ten series connected 225 mA-hr cells which received a continuous charge of 20 milliamperes from the RPG.

Timing and logic for control of the data acquisition and transmission was such that with normal RPG voltage, the Loran would be activated and connected to the HF antenna through normally open coaxial relay contacts ten minutes after conclusion of the last data transmission. The Loran, a dual channel automatic acquisition "Northstar 2000" model manufactured by Digital Marine Electronics Corporation, required less than 50 seconds to acquire one of the pre-selected stations and provide the binary coded decimal data output (16

bits) to low power TTL data latches for storage. In order to conform to the available power, the two channels were selected alternately on successive data transmissions.

The Loran was turned off after 52 seconds and the HF transceiver, a Stoner Model SSB-100 B, was turned on to await receipt of a tone-coded data request from the shore station. Simultaneous recognition of the two request tones triggered a data transmission by keying the transmitter and supplying power to the data acquisition and signal conditioning system power supplies. After 7.5 seconds, the transceiver and power supplies were turned off and the ten minute counter reset to start the next cycle. In the event that no data request was recognized within three minutes after transceiver turn on, a data transmission would automatically be initiated.

In order to facilitate recovery of the buoy in the event of RPG failure or inadequate (less than 20 v) RPG voltage to the buoy electronics, provision was made within the timing logic circuitry for stretching the timing cycle to three hours in order to assure that the stored energy within the NiCad battery packs would be sufficient to power the buoy for about five days. Loss of RPG voltage would of course, be automatically recognized by the shore station computer and result in an "alarm" condition at the NAVFAC watch officer's station.

A. 3. 4. 2 Data Acuisition and Signal Conditioning

(a) Ocean Temperature

The design goal which was established for the thermistor ocean temperature measurement system was the ability to resolve temperature changes of less than $0.05^{\circ}C$. Steps which were taken in the electronics circuit design to attain this goal were:

1) use of a highly regulated, stable power supply to provide thermistor current and amplifier power;

2) use of very low drift, low noise instrumentation type operational amplifiers;

3) provision for monitoring thermistor supply voltage and the use of two thermistor amplifier circuits with fixed resistors instead of thermistors in order to observe long term drift effects;

4) arrangement of the thermistors so that half were supplied from the positive power supply output and half from the negative supply voltage in order to minimize any unbalance current in the common return lead to wire junction at the bottom end of the cable;

5) measurement, during each data transmission, of the common thermistor wire junction voltage due to unbalance current in order to refine the calculation of thermistor resistance by the shore station computer;

6) use of a signal multiplexing and analog-to-digital conversion system with 12 bit word length and ± 1/2 bit accuracy (0.05% of full-scale); and

7) in situ calibration of the thermistors after implantation within the cable (see Section A.1.2.3).

The net result of these design and calibration steps was a thermistor measurement system with a resolution at the data transmission output of about 0.02°C for temperatures of the order of 0-10°C, decreasing to about 0.04°C for temperatures of 30°C. This resolution limit was established by the 12 bit resolution capability of the A-D converter. Signal conditioning drift was low enough to allow 0.01°C resolution.

(b) Tensiometer

In order to establish the exact depth of the thermistors, a tensiometer link was installed at the base of the buoy and attached to the mooring cable. The tension was measured using a two active element temperature compensated semiconductor strain gage bridge which was calibrated over the range from zero to 7500 pounds tension for full-scale amplifier output. The amplifier output was tied into the data multiplexer for transmission to the shore station. Included in the potted tensiometer link package was a thermistor for monitoring surface water temperature. In addition to its use in computing corrected thermistor depths, the cable tension measurement was used to verify the integrity of the mooring with limits used to control activation of the "alarm" indicator at the shore station in the event of three successive out of limit tension measurements.

(c) Inclinometer

An inclinometer package was installed at the lower end of the thermistor cable to provide two orthogonal measurements of cable inclination as inputs to the computer program for further refinement of the thermistor depth correction calculation. The basic sensing elements of this package were two Columbia Research Laboratories Model 701 Inclinometers with combined nonlinearity, hysteresis, resolution and non-repeatability of less than 0.07 degree, a temperature sensitivity of less than 0.003 degree per degree F (which poses no problem at a 1500 meter depth), and a natural frequency above 55 Hz which precludes problems due to

vibration or cable strumming. Absolute value circuits were used to eliminate the negative voltages since the analog-to-digital conversion in the data encoder accepted only positive signals (the sign of the inclination was unimportant).

Power for the circuitry and sensors was provided by a small NiCad battery pack which was trickle charged by the RPG. During data transmission a SPDT relay in the buoy electronics was energized to disconnect the RPG voltage. This caused a transistor switch in the inclinometer package to connect the battery pack to dc/dc converters supplying power to the sensors and associated electronics.

(d) Data Formatting

Because of the intent to deploy the Sea Robin IV buoy at greater than line-of-sight distances from the shore station on Eleuthera, a high frequency transmission link was required. Frequency shift keying was selected as the most efficient and reliable mode of data transmission. Frequencies of 2000 and 1500 Hertz were selected as permitting a reasonably rapid bit rate of 156.25 bits per second (chosen because of its being an integral submultiple of the basic 10 kilohertz clock frequency used for Sea Robin III and within the above station). A basic sixteen bit data word length had previously been adopted for use with SR-III and was, therefore, carried over to SR-IV.

The first twelve bits are data bits (compatible with the analog-to-digital converter and the PDP-8/e shore station computer), followed by a parity bit and three word sync bits for error detection. Only one frame of data is transmitted during each buoy transmission period because of available power limitations previously discussed in Section A.3.4.1. The entire frame contains 48 words preceded by two seconds of bit clock data rate to allow transmitter warm-up and phase lock of bit clock in the shore station data decommutator.

The first data word is a frame sync word (also used by SR-III) to synchronize the word counter at the shore station. This is followed by the eighteen thermistor cable temperature measurements, cable unbalance current measurement, the inclinometer and tensiometer data, the Loran position fix and channel identification and a variety of housekeeping information including battery, RPG and dc/dc converter voltages and thermistor reference amplifier outputs.

The data multiplexing and conversion system was built around a Datel Corporation Type

DAS-16-L12B, with three additional MM-8 multiplexers to expand the system capability to 39 analog data input capability. Standard commercial grade TTL logic is used to provide control and digital data formatting.

(e) Data Transmission

Data transmission and receipt of data request commands were accomplished with a Stoner Model SSB-100B single-sideband transceiver operating at a frequency of 3319 kilohertz and delivering about 50 watts to the antenna during data transmission. The transceiver has four channel capability within the frequency range of 2-15 megahertz to allow for different frequency requirements which may be required in a subsequent redeployment at a diferent location and under various radiowave propagation conditions.

A center-loaded twenty foot long, adjustable tip-tuned, 1 1/2 inch diameter aluminum stub antenna located at the top of the buoy mast was connected to the transceiver through a lightning arrester and normally closed coaxial relay contacts. The antenna relay was energized when the Loran was turned on in order to connect to the Loran through an antenna tuning network.

A.4 ELEUTHERA SHORE STATION

To minimize buoy power requirements and to allow use of existing VHF hardware on the Sea Robin III, a shore station to operate and receive data from the buoys was installed at NAVFAC Eleuthera. A surplus communications van was refurbished and installed on a bluff at the naval facility (see Figure A-22). It should be noted that the cooperation and assistance of the commanding officer and staff at NAVFAC Eleuthera were outstanding without which the shore station operation would have been a difficult task at best.

The van provided structural support for the VHF and HF antennas and, with suitable air conditioning, housing for the electronic systems. During field operations the shore station also provided a communication center for the ships involved, furnishing weather and other safety information.

A.4.1 Shore Station Software Electronics

The shore station was designed around a DFC PDP 8/e minicomputer. This computer, equipped with 8K of memory, a power fail/auto restart control, a 1 Hz internal clock and several forms of programmable input/output channels (see Figure A-23). Programs and data stored on a DEC tape unit.

Radio frequency signals to and from the buoys interfaced to the computer through four specially constructed intermediate units. The first of these decoded the data coming from the buoy from aerial to 12 bit parallel from where it was fed to the computer. The command generator used digital data commands to select groups of output tone commands. The R.F. controller provided the power switching and keying of the transceivers. Finally, the multicoder took data from the computer and provided FSK modulation of aerial data for transmission to the Valley Forge monitor. Since both the transceivers and the computer were strong sources of R.F. Noise, the interface units also provided line isolation. Further, note that it was important to prevent constant keying of the transmitters should the computer halt or be interrupted after transmission initiation. Hence all keying was turned off so that positive computer command was needed to maintain transmission.

Since the shore station was ideally located on a bluff with almost total visibility both seaward and across the banks, it was convenient to locate wind sensors on the van. These were preprocessed by a signal averaging unit and the data sampled when buoy data was received.

Manual readout of the shore station was performed by a conventional video readout unit. Hard copy of both raw and processed data could be achieved for short periods using a venerable ASR 33 teletype.

One major problem with the shore station was that it depended on power from the naval facility. There were a number of power outages during the early days of the shore station operation and it was necessary to provide an external time reference independent of the power supply. A simple 24 bit binary clock, powered by NiCad batteries, was constructed and a section of computer program written to convert to ZULU time.

A second problem resulting from power loss was that the transceiver crystal ovens were not maintained at temperature. On power up the transceivers were below operating frequency and could miss a data block. This only occurred on two occasions when power loss was many hours in duration.

Because Sea Robin IV was powered by a nuclear device, the computer operation was monitored by NAVFAC operators. To facilitate this an alarm readout was installed, thereby allowing 24 hour monitoring in the operations center.

A.4.2 Shore Station Programming

The software for controlling the shore station was written entirely in machine language developed and maintained by the GE real-time interactive monitor. In order to minimize program development time, the program was coded manually in a modular fashion and typed into memory using XOD. XOD is an acronym for eXtended Octal Delong program which is used primarily to access a running program for debug purposes.

Examination of Figure A-24 will reveal the structure of program flow. Most of the time is spent waiting for clocks to time-out. Although the console keyboard is "live" during waiting periods, it is "locked out" during critical procedures to prevent loss of data. Operator commands include requests to print buoy or meteorological data, initiation of DEC tape replacement or access to XOD for program maintenance.

When a set of data from the buoy was received, checks were made on voltage levels within the block to verify validity, then a set of environmental parameters was obtained from the van Met package which included wind and local temperature readings. These data were

stored on tape along with buoy data and clock information. Subsequent to storage, the program initiated preliminary reduction of the raw data to engineering units, so that at any time an operator could read out the most recent set of data from memory.

The basic program loop consisted of examining a rotating priority list to determine which phase of program flow was due for processing. The "processing due" indication was set into a location called FLAG by the clock routine, under control of the program interrupt procedure. The FLAG word was examined for presence of a set condition on each of several bits which indicated:

(a) request data

(b) transmit data to Valley Forge

(c) reduce data in memory

(d) examine keyboard for operator request

The data request bit (a) was set by timeout of a 12-minute counter and reset after each successful data reception. The transmit flag (b) was set once daily after receipt of data at 0700 GMT. The reduce data flag (c) was set upon validation of received data, and the keyboard flag (d) was set upon operator request.

In order to avoid program hang-ups due to hardware failures, the concept of a kick-out dock was used to monitor data acquisition. At the initiation of a data request, a timer was set in software which was monitored during the wait cycle. If data were not received within a prescribed time frame, the program would exit from the loop.

Once data were received, a validation test determined if the values of certain fixed parameters fell within desired limits. If so, the "compute bit" was set. Then data were acquired from the Met package on the van, the block was labeled with current time and data information and written to DEC tape. Then the current block of raw data was converted into engineering form and stored in memory for access by the operator.

The data reduction equation was derived from the response characteristics of the metal-junction thermistors, whose performance was monitored during the cable fabrication period in the laboratory. After each thermistor was moulded into the cable, it was subjected to a

temperature cycle in a saltwater bath, and data were recorded under computer control. Then the response was compared to a known thermistor and a least-squares method used to obtain coefficients of best fit to the equation.

A.5 AUXILIARY EQUIPMENT

In addition to the buoy systems certain auxiliary equipment was necessary for the total program. A facility was installed at Valley Forge to monitor the shore station operation on a daily basis.

Field operations included bathymetry before and during launch at the Sea Robin III site. Some prelaunch bathymetry was also performed. For these operations special apparatus was constructed.

A.5.1 Valley Forge Monitor

The Valley Forge Lab System comprised another PDP 8/e, which had 16K of memory, all modules incorporated in the shore station (to facilitate program maintenance) and additional peripherals including dual-DEC tape, a high-speed paper tape I/O unit (HSR/HSP), dual cassette (DEC), Datel cassette reader, 7 track mag tape and dual floppy disk. This system was set up to provide both program development, since the shore station was installed some 18 months prior to final deployment of Sea Robin, and final reduction of received data. Programming was done both at the assembly language level using FOCAL (a DEC proprietary language, featuring capabilities of FORTRAN and BASIC, and operating in an interpretive mode). Using a program coded in FOCAL, the raw data was read from DEC tape, converted to engineering units, then sent on-line to a Honeywell 6060 time sharing system for subsequent processing into graphical form.

Another phase of implementation was monitoring the shore station. The shore station was set up to broadcast data to Valley Force daily in order to provide indications of proper operation. The Lab System was left in the receive mode at the end of each workday and the data transmission took place at 0700 GMT (a relatively "clean" transmission time, avoiding other traffic on that frequency and taking advantage of ionospheric bounce). On the following morning the received data would be examined to monitor the integrity of the system.

A.5.2 Acoustical "Fish"

The Acoustical "Fish" is a below waterline carrier for a variety of acoustical bathymetric transducers and hydrophones. An aluminum alloy platform on which the instruments are mounted is housed in a low drag fiberglass shell. The entire assembly is supported on

tubular struts welded integrally into a framed structure for rigid positioning alongside of a selected workboat. The fish is readily adaptable to either large or small vessels. See Figures A-25 and A-26.

The fiberglass housing is constructed such that the upper half of the cylindrical shell is removable for installing and servicing the acoustic components. Openings in the shell, strategically located, facilitate the initial filling with water and exhausting of air upon submergence of the fish. The water remains quiescent within the fish even when underway so as as to minimize acoustic interference.

Mounted within the fish are two directional AMF-Sea Link hydrophones, a Model 200 for use with Model 242 Acoustic Release/Pingers and a Model 301 (special) for operation with Model 322 Acoustic Release/Transponders. Also installed, are three Raytheon bathymetric transducers used for depth sounding and bottom mapping. Two of these are narrow beam 24 kilohertz units employed to survey irregular regions at moderate depths; the third (not yet installed when the photo in Figure A-25 was taken) is a high powered 12 kilohertz transducer (2000 watts) for use in the deep ocean where high resolution is less critical. Shipboard equipment for the various acoustic generators process, respond to and/or record the resultant signals.

REFERENCES

A1 Hoppmann, R., Cable Sealing Tests at NRL High Pressure Test Facility, GE-RESD PIR-9521-FRK-645, 5/7/73.

A2 Hoppmann, R., Test of Sea Robin III Thermistor String in Underwater Test Facility, GE-RESD PIR-9521-FRK-646, 5/10/73.

A3 Pavlak, A., Softley, E. J. and Hoppmann, R. F., A Thermistor String for Use in the Deep Ocean, GE-TIS 71SD246, 8/18/71.

A4 U. S. Navy Marine Climatic Atlas of the World, Vol. I, Atlantic Ocean, NAVAER 50-1C-528, 11/55.

A5 Hogben, N., Lumb, F. E., Ocean Wave Statistics, Her Majesty's Stationary Office, 1967.

A6 James, R. W., Ocean Thermal Structure Forecasting, Naval Oceanographic Office, SP-105, ASWEPS Manual, Vol. 5, 1966.

A7 Maloney, W. E., A Study of the Antilles Current Using Moored Current Meter Arrays, Naval Oceanographic Office, Wash. D. C., 1967.

A8 Pratt, J. S., Gray, E. L., Analysis and Computer Program Describing the Dynamic Planer Motion of a Surface Buoy, GE-PIR-2A20-000-058, 1971.

A9 Lanieuski, J. P., Bain, J. A. and Croshaw, P. F., "Sea Robin" Moored Buoy Development, GE-REDC S671069, 12/30/66.

A10 Matlock, C. E., Jr., Sea Robin, An Ocean Buoy/Satellite Communications Experiment, GE-RESD 70SD206, Jan. 1970.

A11 Stange, W. F., Proof Test of Controlled Taper Fairlead, PLP Marine Sys. Div. Tech. Rpt., MTR-198, Mar. 1974.

A12 SNAP 21 Shipping and Handling Manual, 3M Co., MMM-3691-42, Mar. 1970.

A13 Rosell, F. E., Jr., Softley, E. J., Engel, M. J. and Ranes, G. J., Safety Analysis, ONR Sea Robin IV Buoy Project Utilizing a Radioisotopic Power Generator (RPG), NNPU, GE & ONR, Sept. 1974.

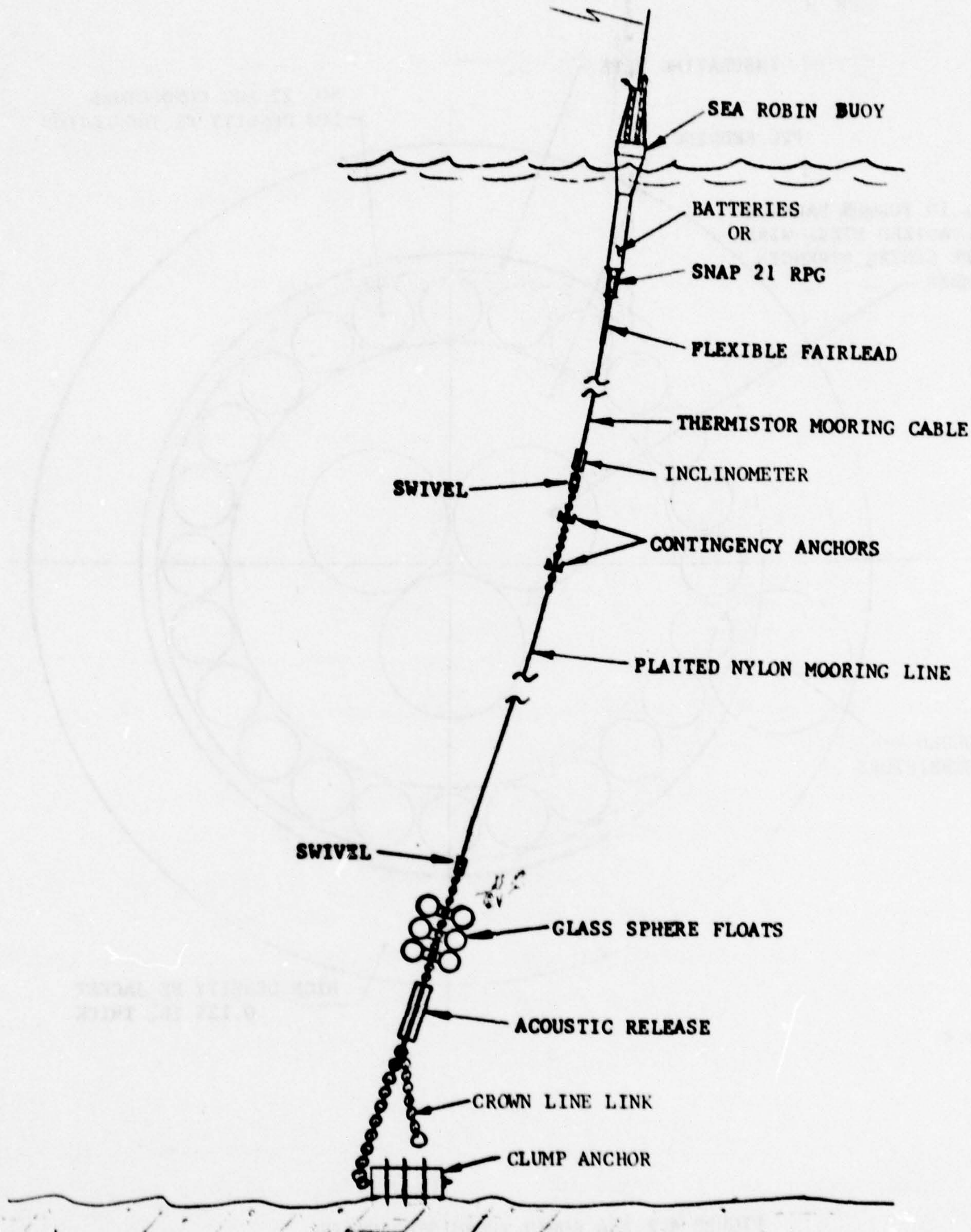


FIGURE A-1 BUOY AND MOORING CONFIGURATION

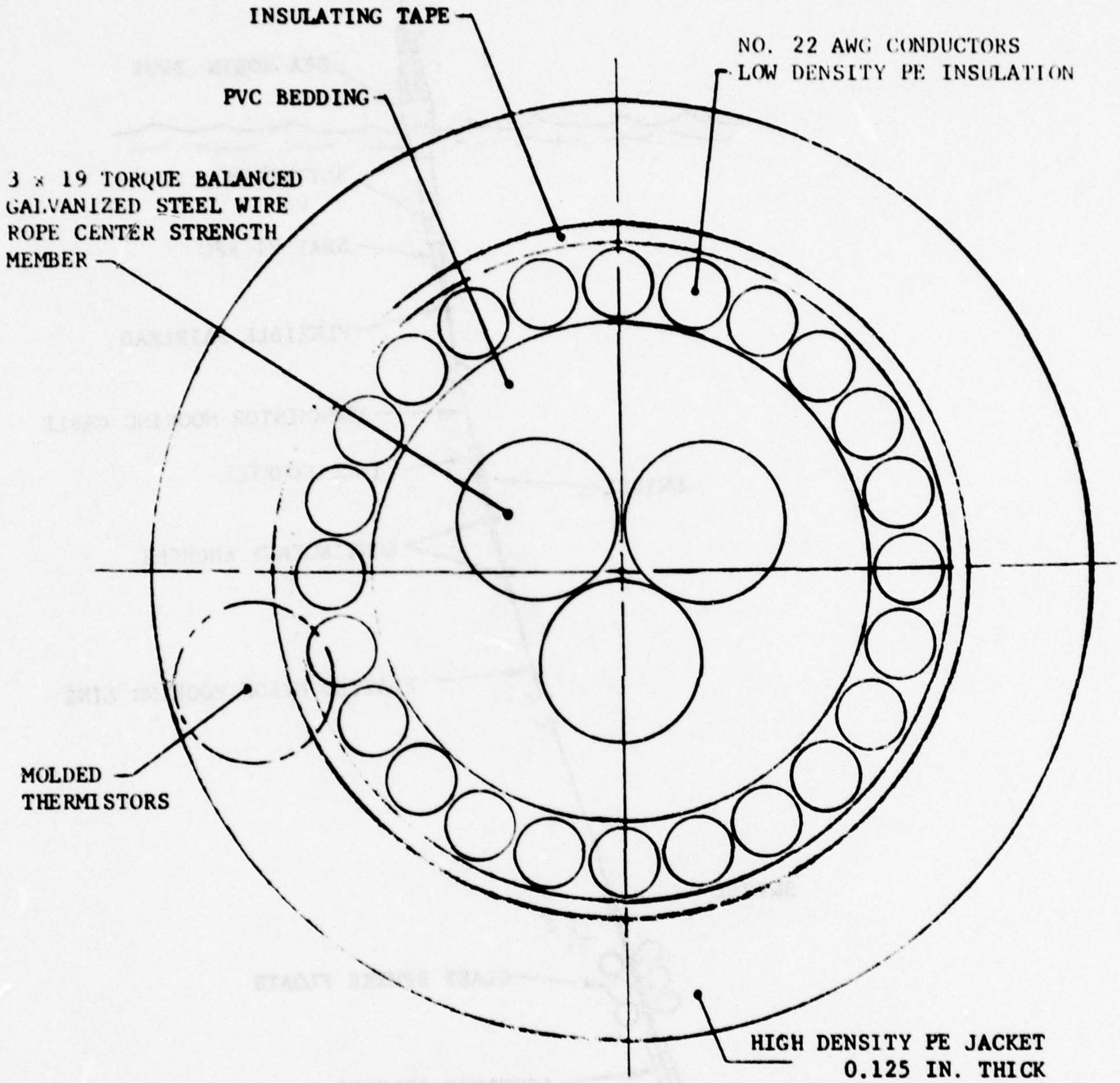


FIGURE A-2 SEA ROBIN THERMISTOR STRING

FIGURE A-3 THERMISTOR CABLE

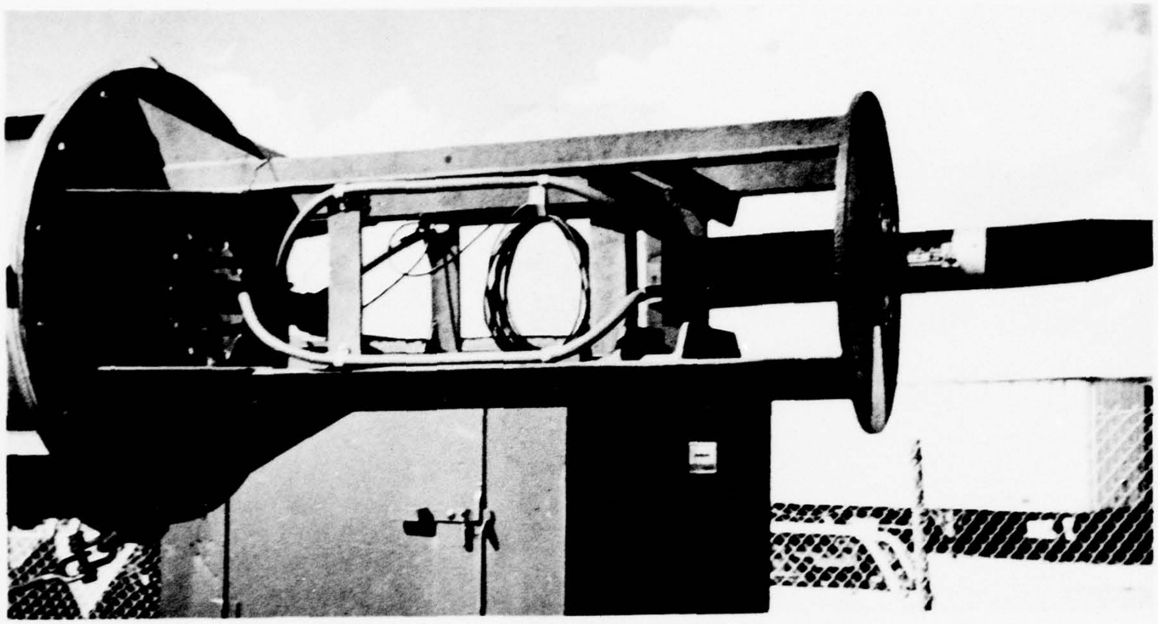
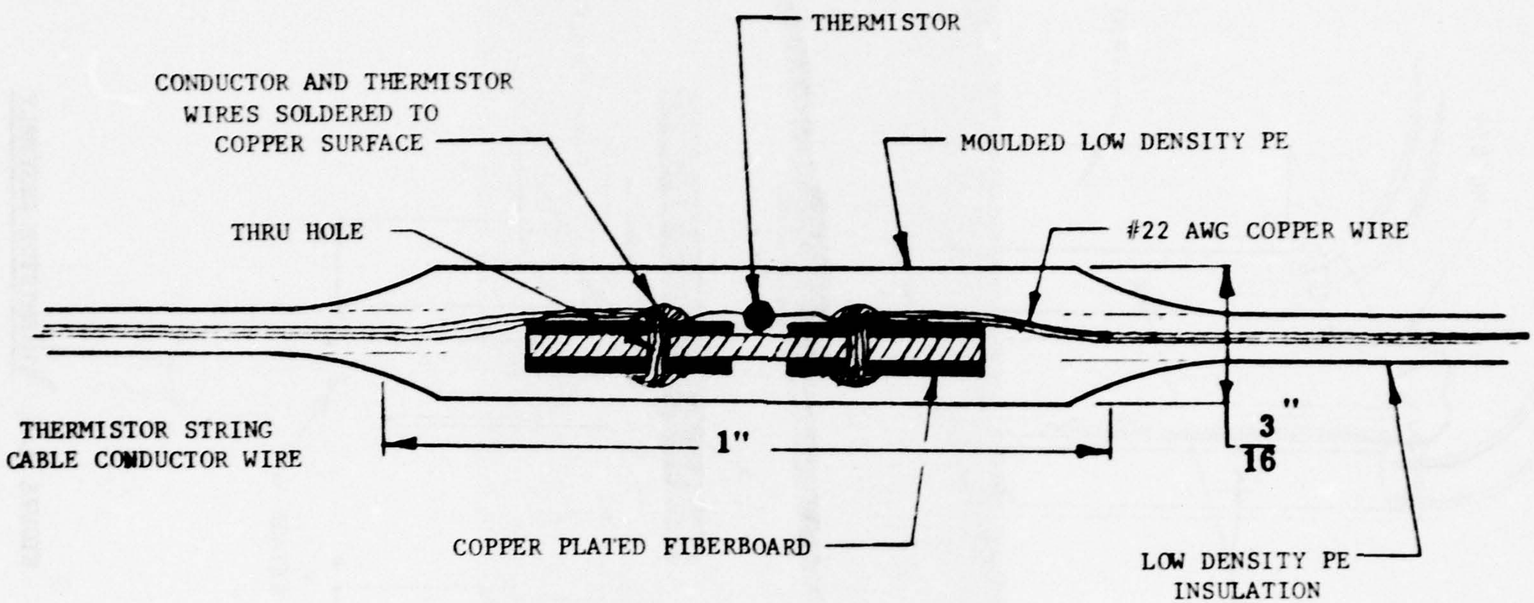


FIGURE A-4 <u>BUOY FRAME STRUCTURE</u> - Showing Upper Mooring Attachment with Cable Conductor Bundles Extending into the Buoy Hull thru the Connector Box (RPG Power Supply Not Installed).



MOULDED THERMISTOR CONSTRUCTION

FIGURE A-5

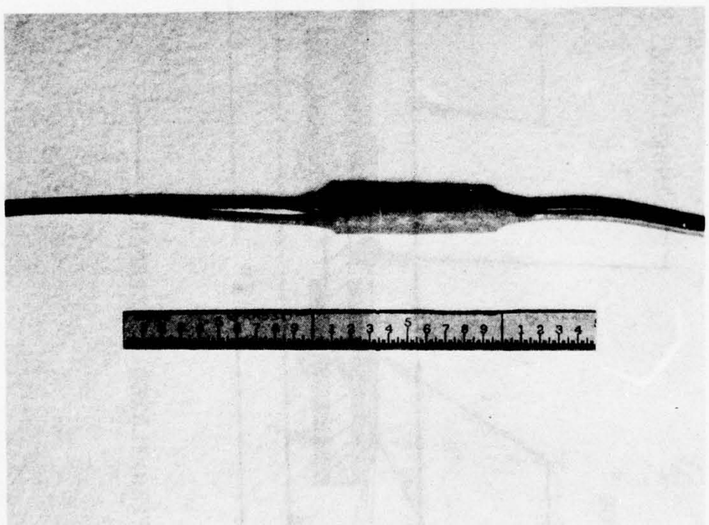
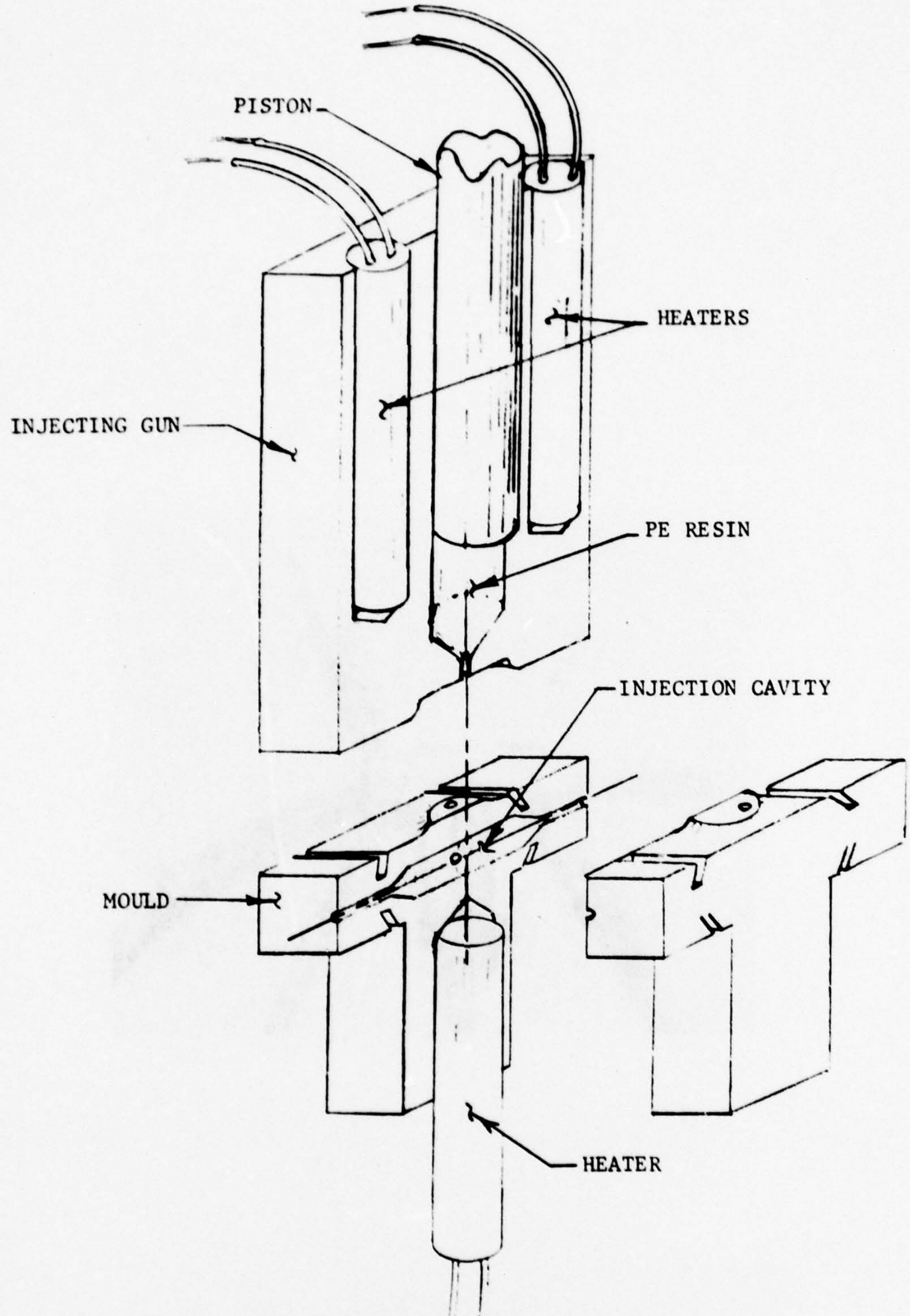


FIGURE A-6 THERMISTOR ASSEMBLY



<u>INJECTION MOULDING EQUIPMENT</u>
(COOLING PASSAGES NOT SHOWN)

FIGURE A-7

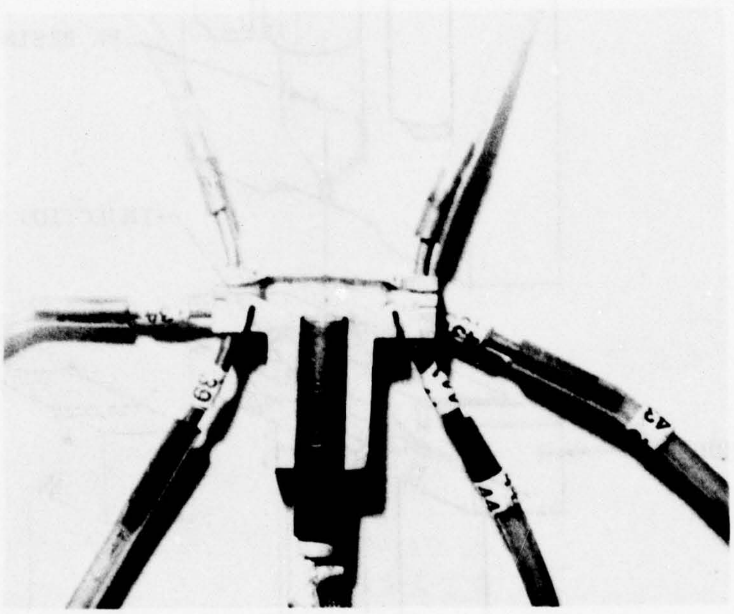
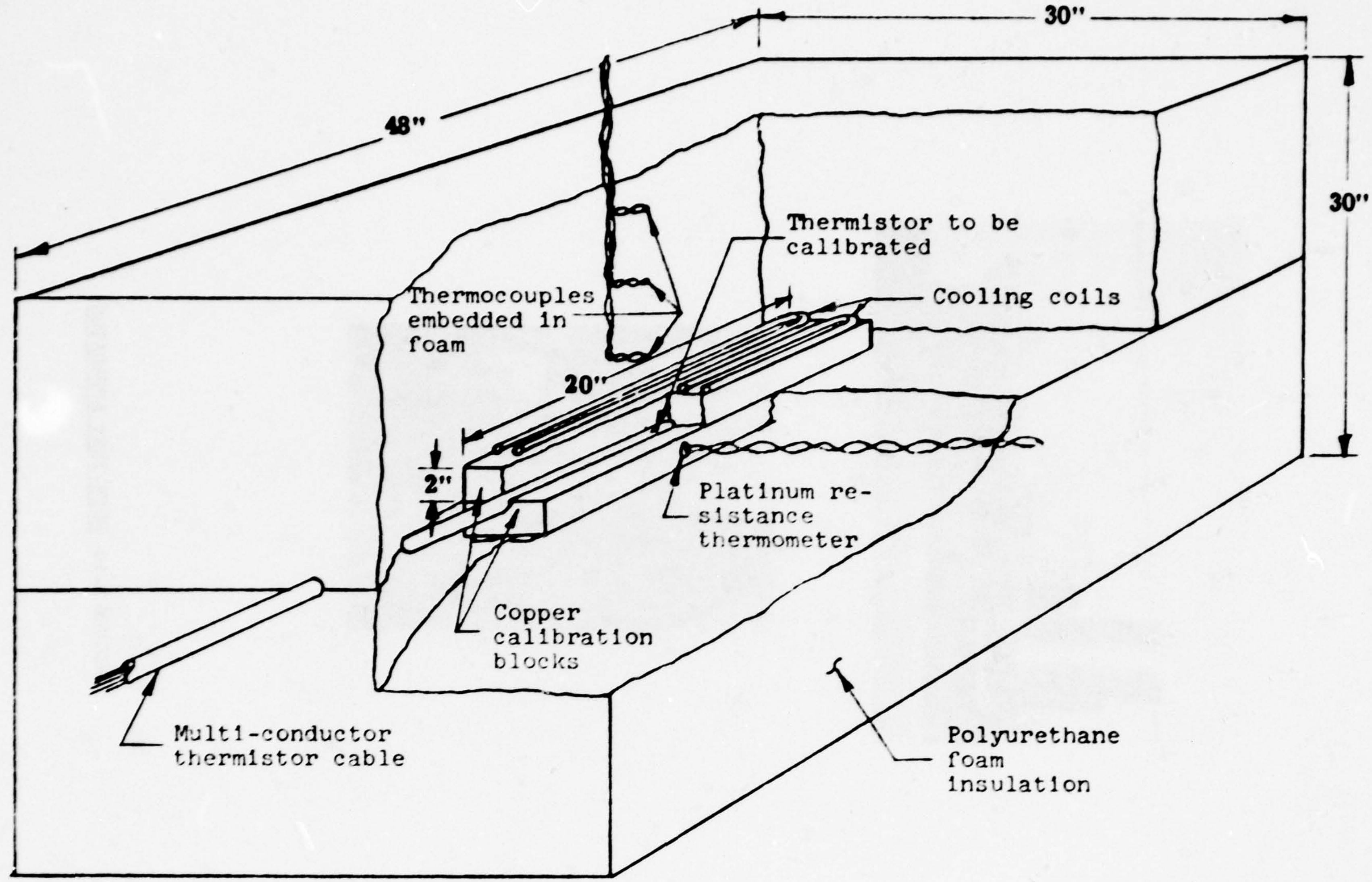
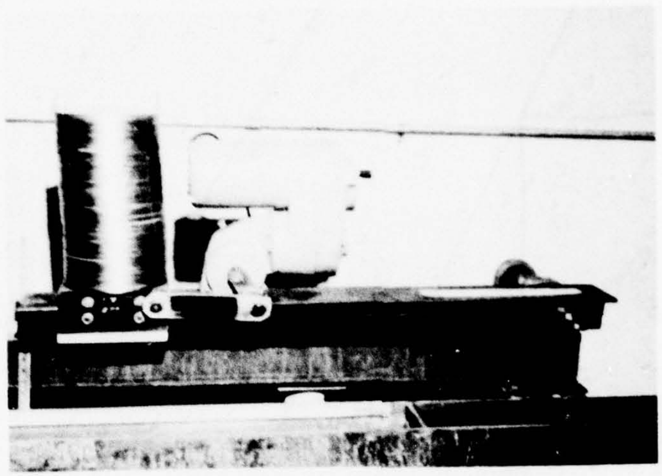


FIGURE A-8 THERMISTOR MOULD



THERMISTOR CALIBRATION APPARATUS
FIGURE A-9



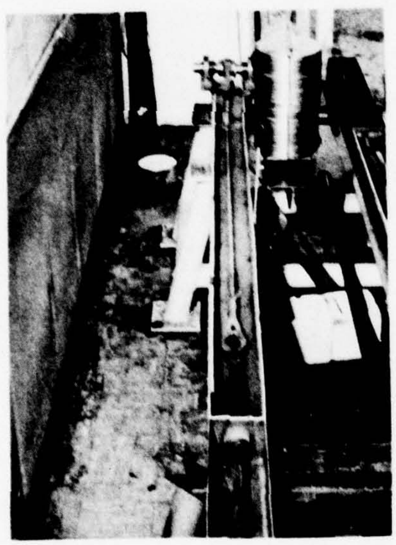


FIGURE A-10 ROPE TEST APPARATUS

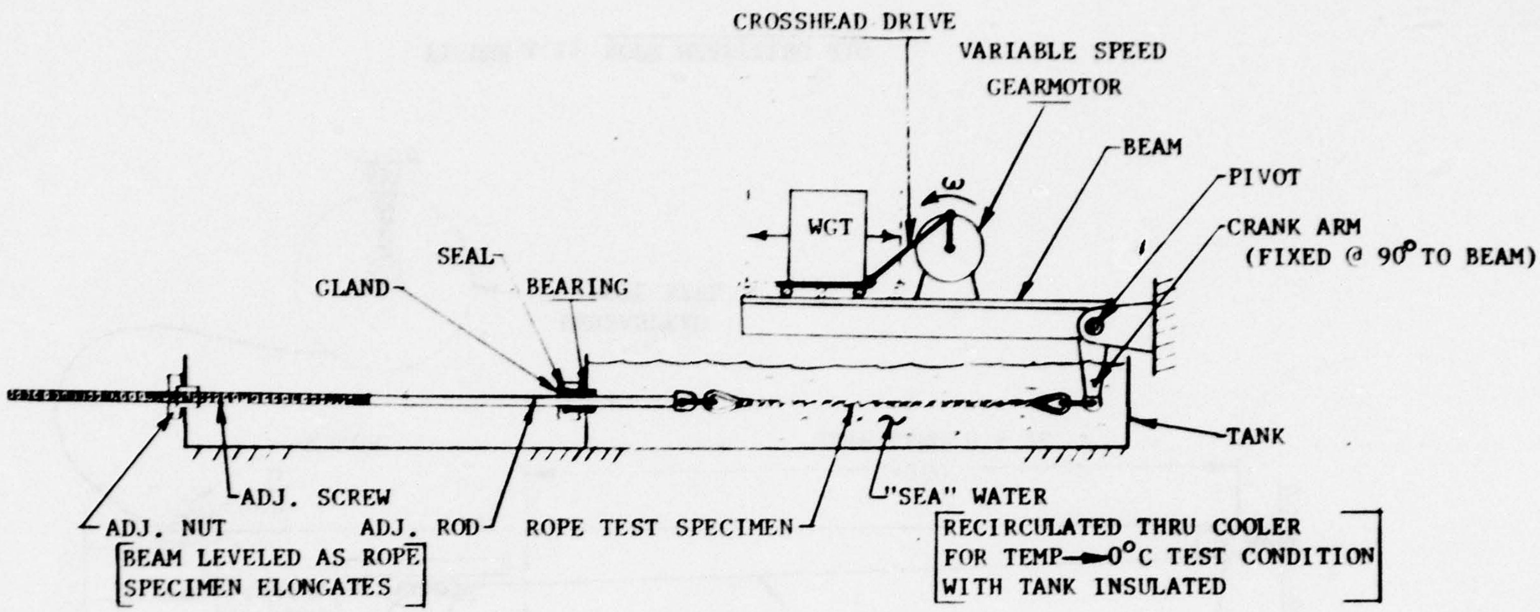


FIGURE A-11 ROPE TEST SCHEMATIC

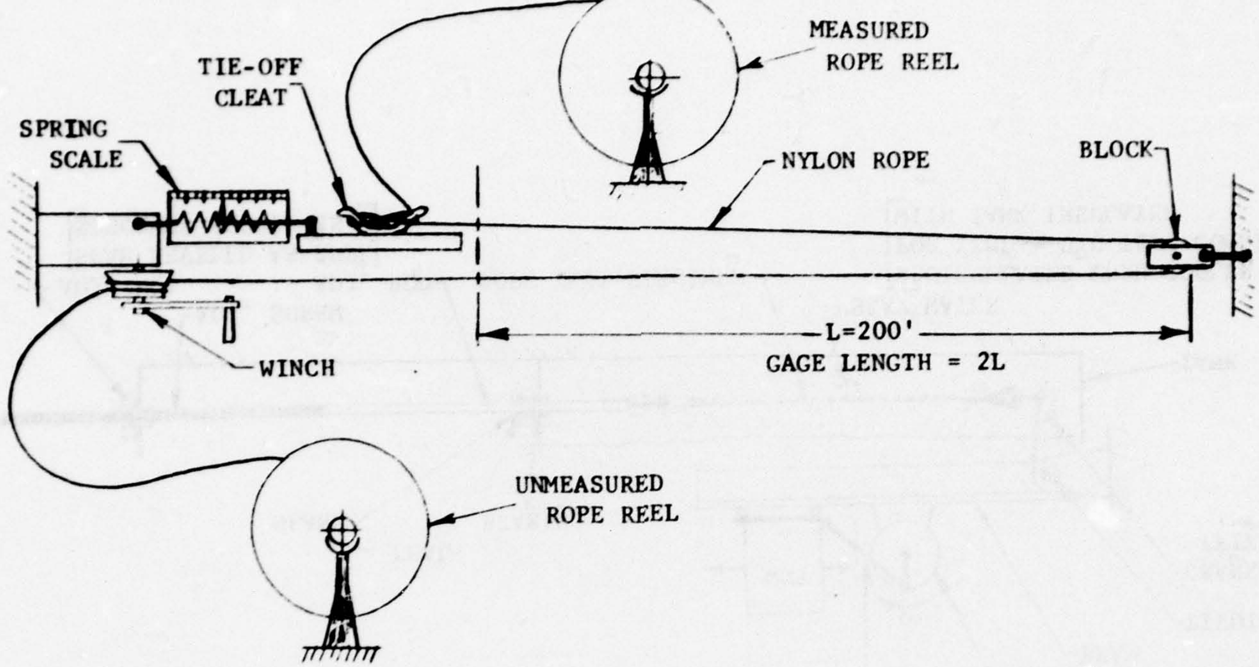


FIGURE A-12 ROPE MEASURING RIG

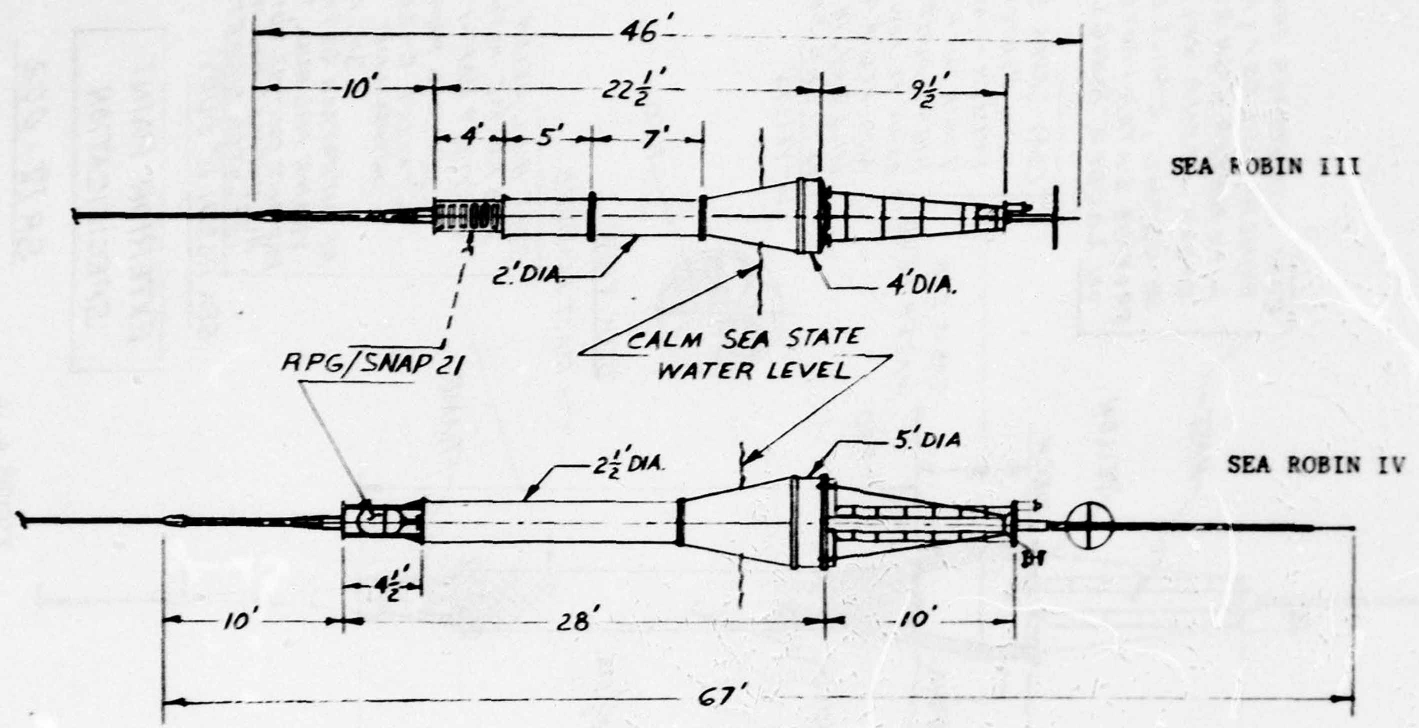


FIGURE A-13 SEA ROBIN BUOY CONFIGURATIONS

SPEC. NO. SR IV-002

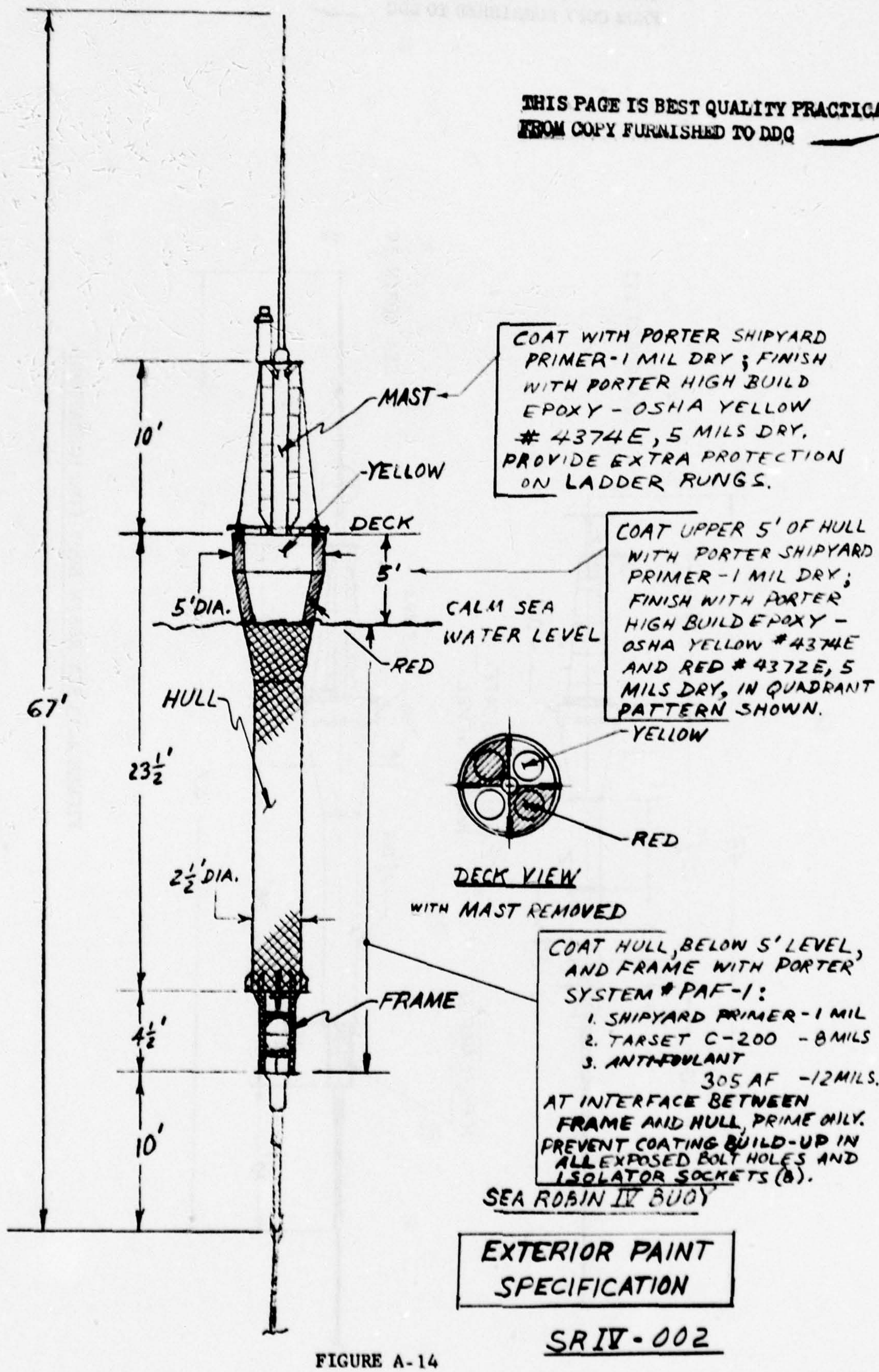


FIGURE A-14

M.J.E. 5/20/74

SEA ROBIN BUOY
COMMUNICATION TEST CONFIGURATION

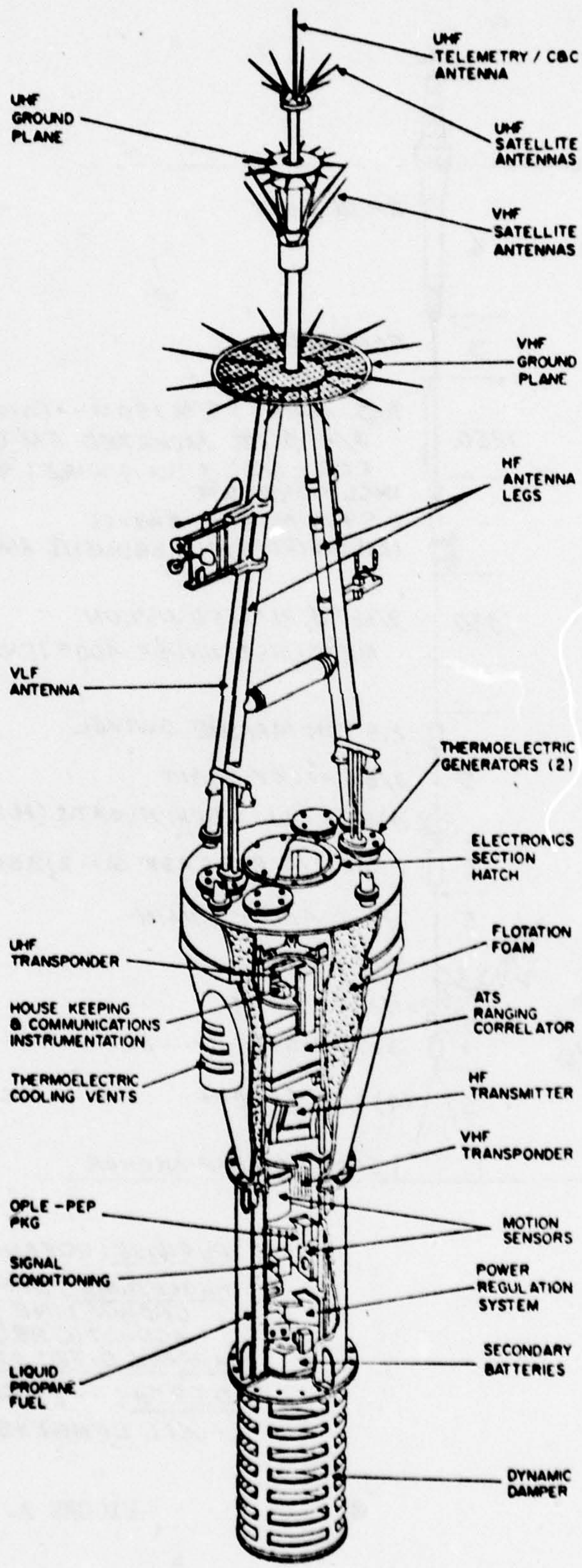


FIGURE A-15

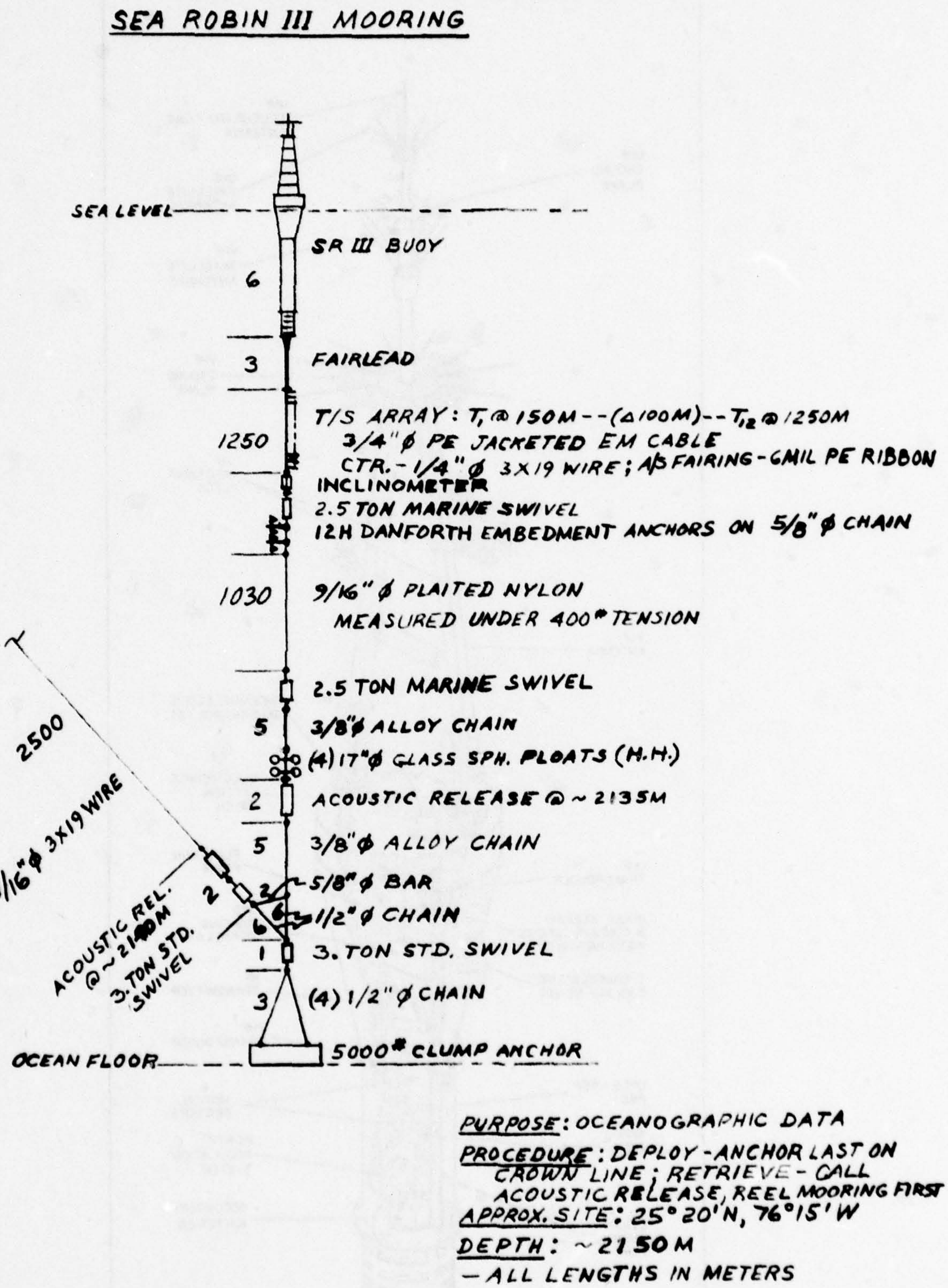

SEA ROBIN III MOORING
SEA LEVEL
6
SR III BUOY
3
FAIRLEAD
1250
T/S ARRAY: T_1 @ 150M --(Δ100M)-- T_{12} @ 1250M
3/4" ø PE JACKETED EM CABLE
CTR. - 1/4" ø 3X19 WIRE; A/S FAIRING - 6MIL PE RIBBON
INCLINOMETER
2.5 TON MARINE SWIVEL
12H DANFORTH EMBEDMENT ANCHORS ON 5/8" ø CHAIN
1030
9/16" ø PLAITED NYLON
MEASURED UNDER 400# TENSION
2.5 TON MARINE SWIVEL
5
3/8" ø ALLOY CHAIN
(4) 17" ø GLASS SPH. FLOATS (H.H.)
2
ACOUSTIC RELEASE @ ~ 2135M
5
3/8" ø ALLOY CHAIN
2
5/8" ø BAR
6
1/2" ø CHAIN
1
3. TON STD. SWIVEL
3
(4) 1/2" ø CHAIN
OCEAN FLOOR
5000# CLUMP ANCHOR
2500
7/16" ø 3X19 WIRE
2
6
ACOUSTIC REL. @ ~ 2140M
3. TON STD. SWIVEL
PURPOSE: OCEANOGRAPHIC DATA
PROCEDURE: DEPLOY - ANCHOR LAST ON CROWN LINE; RETRIEVE - CALL ACOUSTIC RELEASE, REEL MOORING FIRST
APPROX. SITE: 25° 20' N, 76° 15' W
DEPTH: ~ 2150 M
— ALL LENGTHS IN METERS

FIGURE A-16

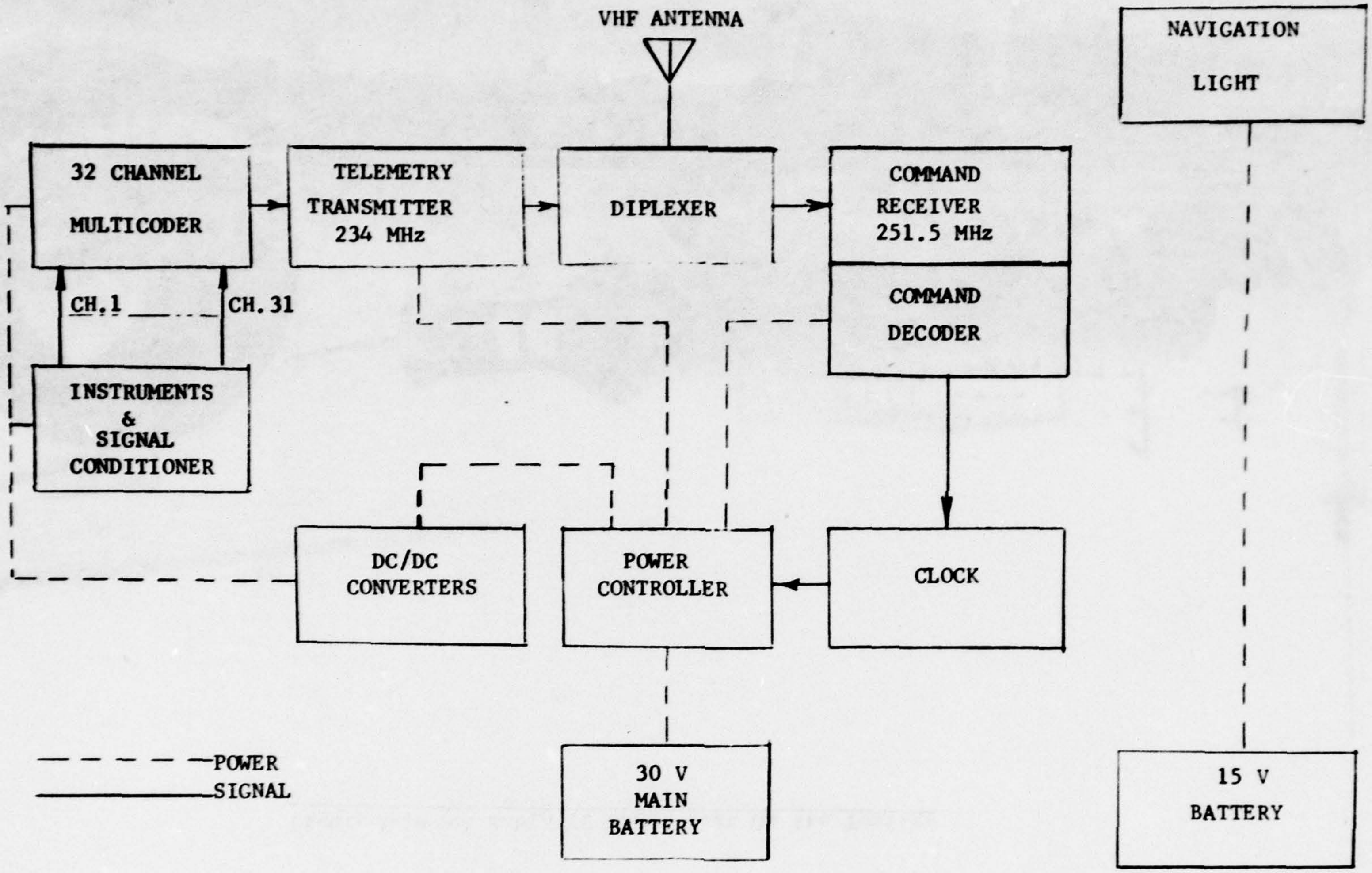
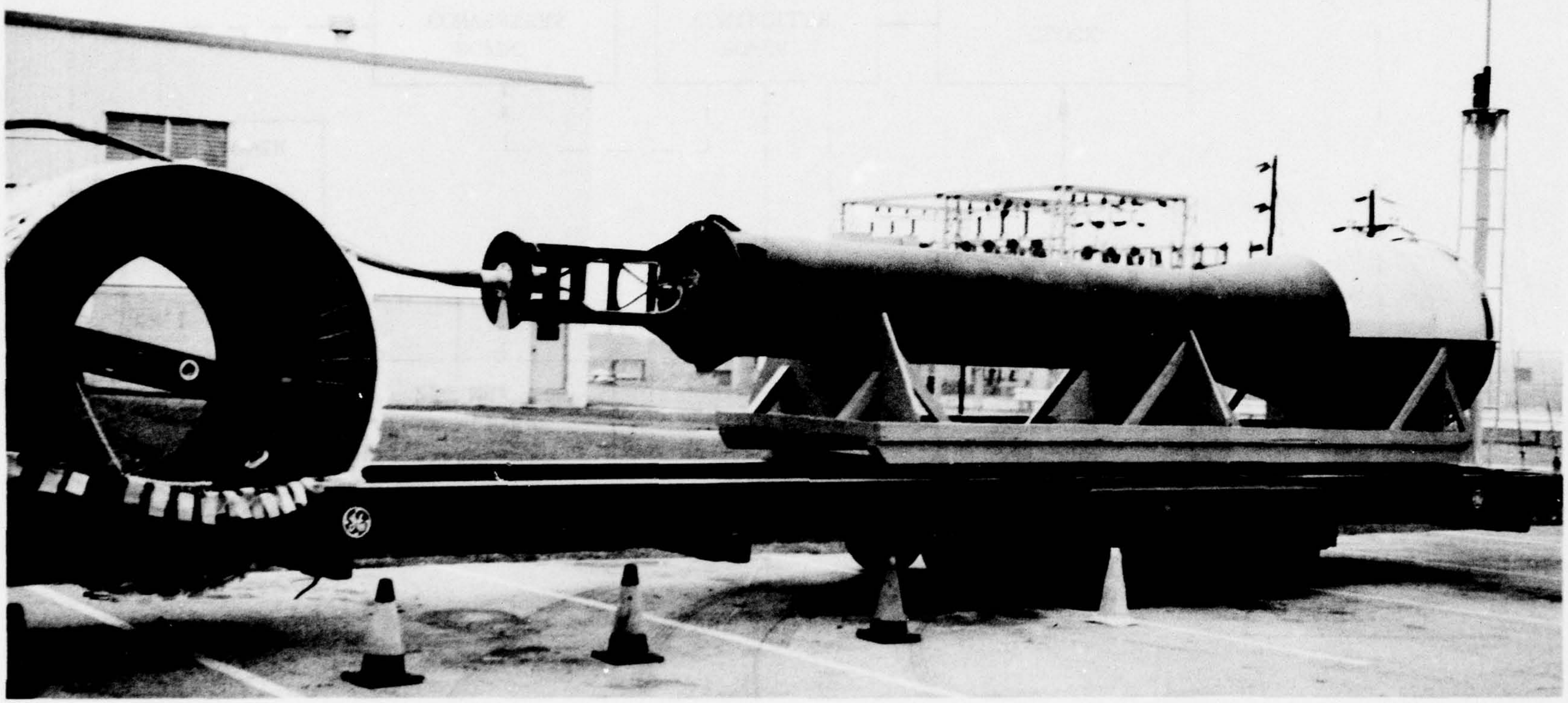
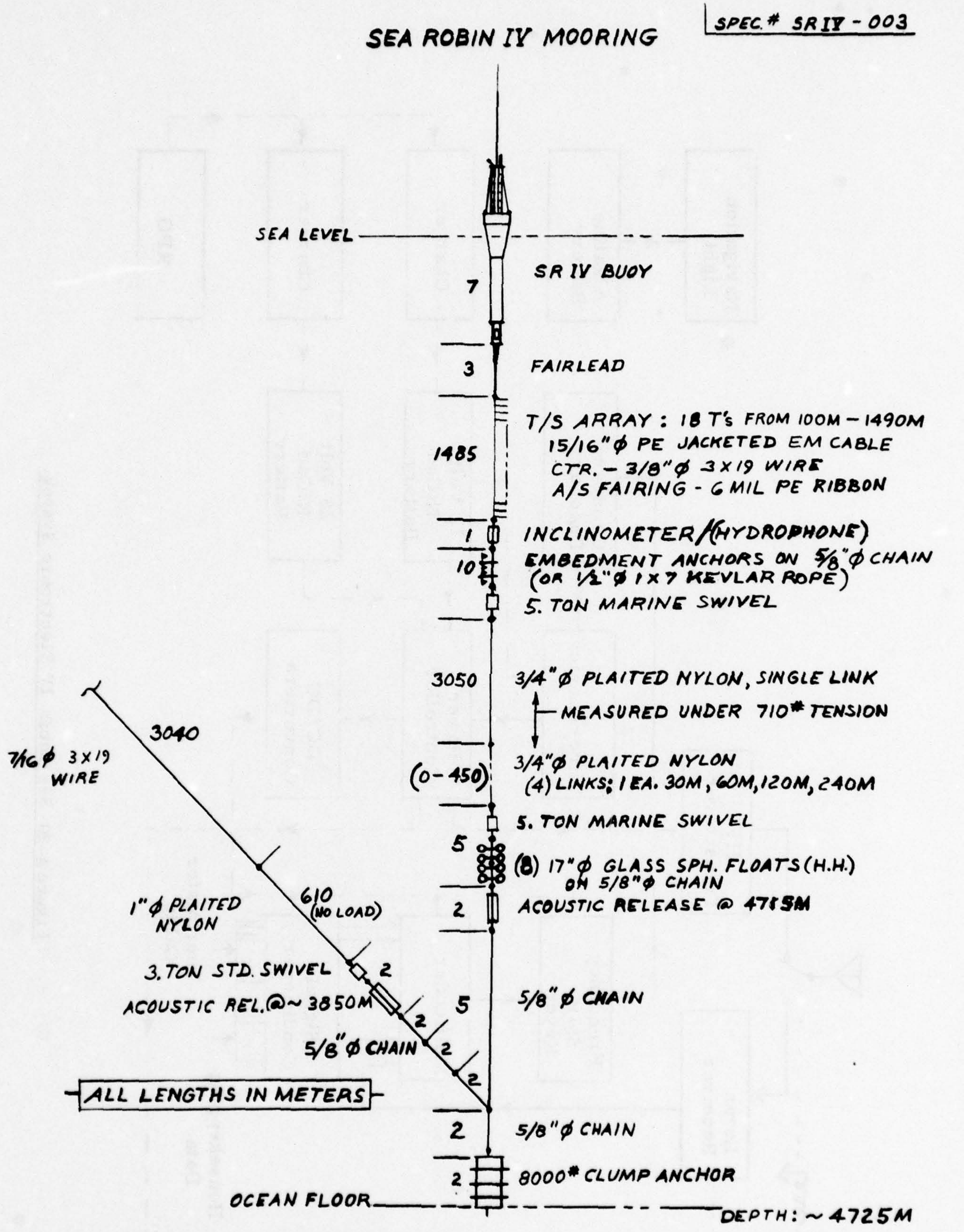


FIGURE A-17 SEA ROBIN III BUOY ELECTRONIC SYSTEM

Figure A-18 Sea Robin IV Under Test On Its Trailer





PURPOSE: OCEANOGRAPHIC DATA

PROCEDURE: DEPLOY - ANCHOR LAST ON CROWN LINE, FREE DROP LAST 875M
RETRIEVE - CALL ACOUSTIC RELEASE, REEL MOORING FIRST

APPROX. SITE: 25°35'N, 75°52'W

MOORING DIAGRAM
SPEC. NO. SRIV-003

FIGURE A-19

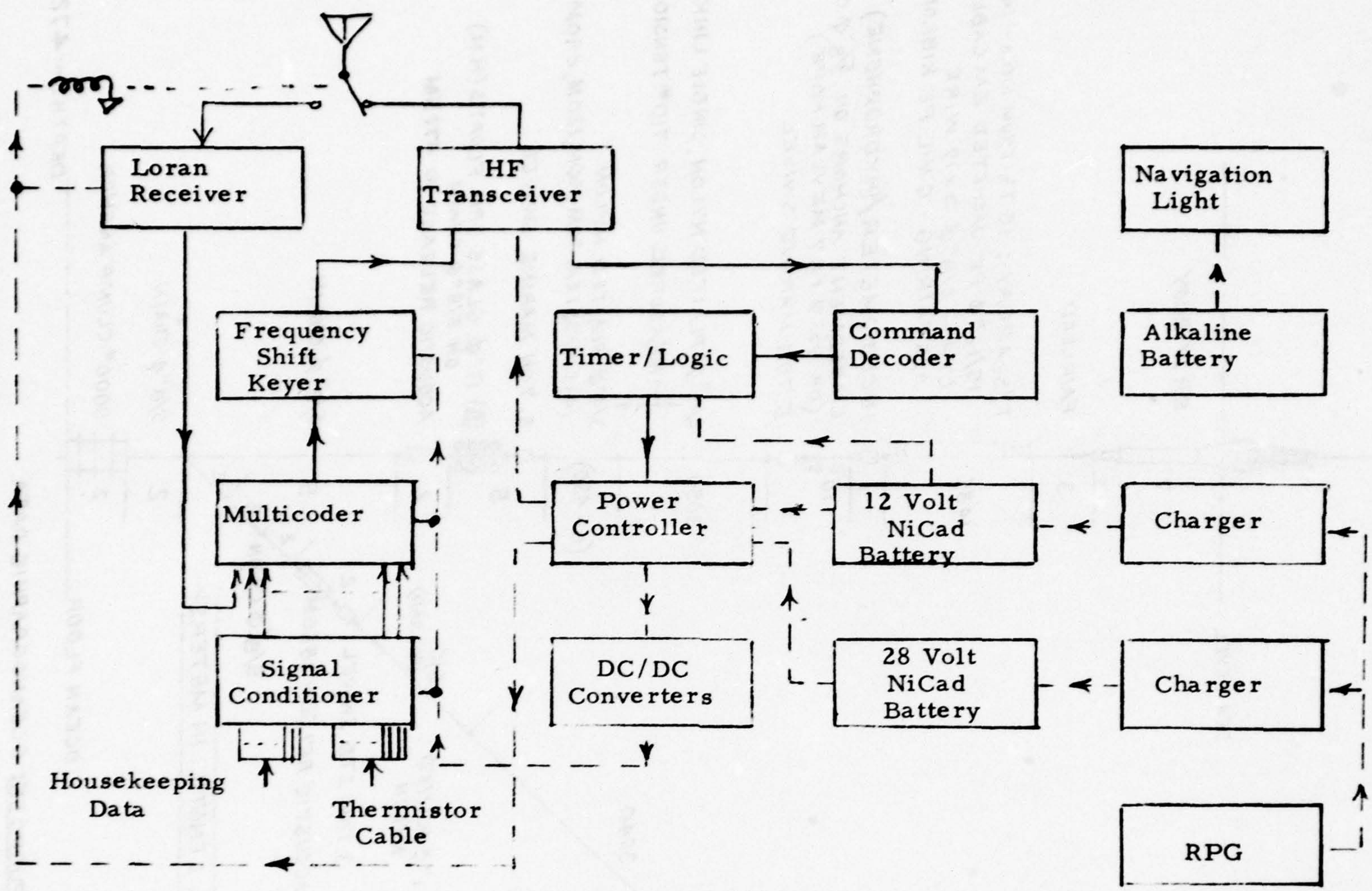
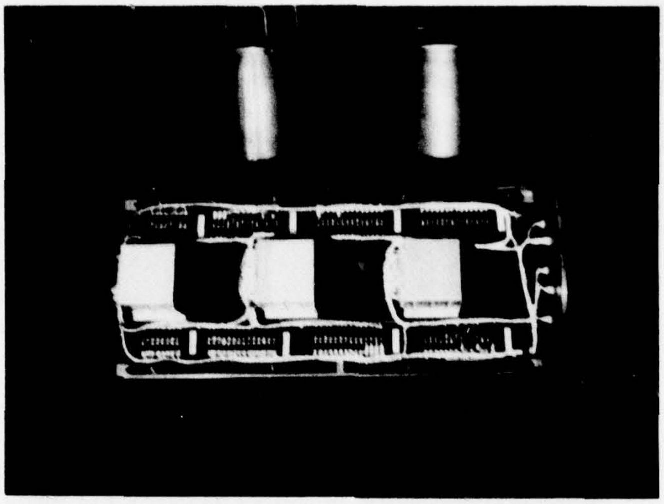


Figure A-20 Sea Robin IV Electronic System.



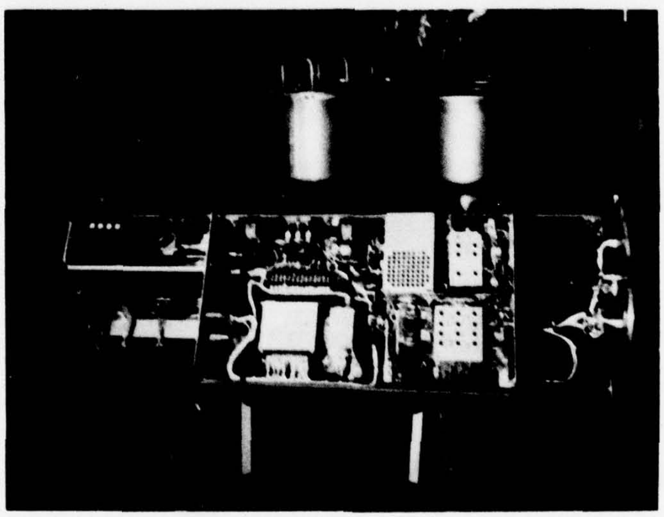


Figure A-21 Sea Robin IV Electronic Assemblies.

Figure A-22 The Sea Robin Shore Station

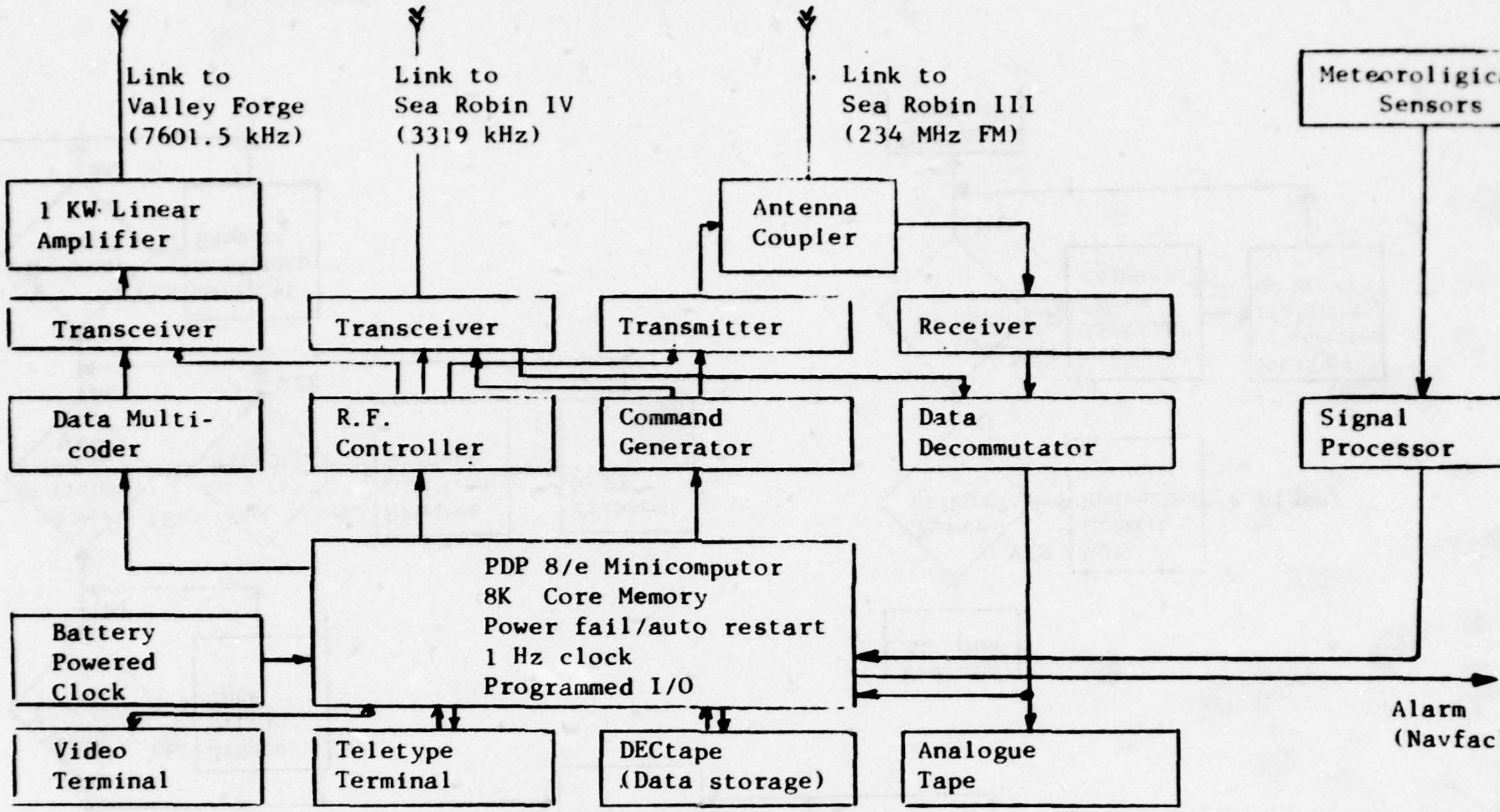


Figure A-23 Arrangement Of Eleuthera Shore Station Hardware.

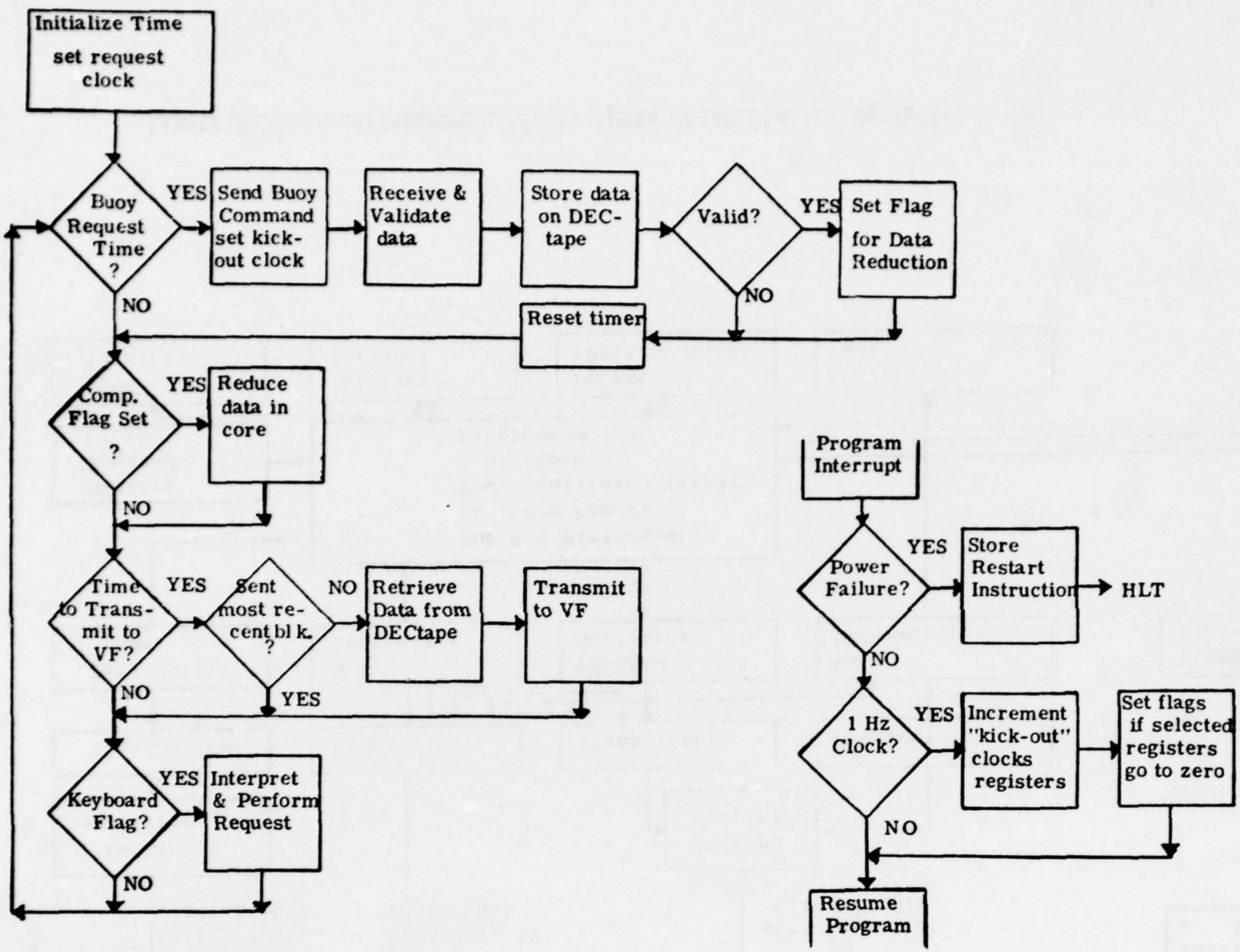


Figure A-24 Shore Station Software Flow Diagram.

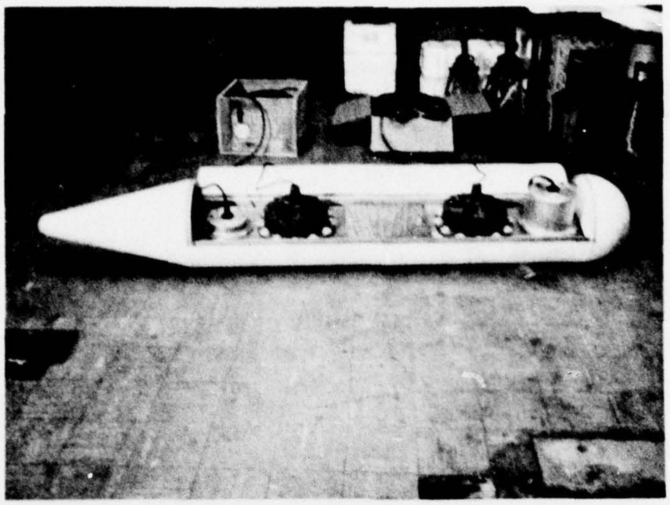


Figure A-25 The Acoustic Bathymetric "Fish" During Assembly And Mounted On The R.V.Venture.

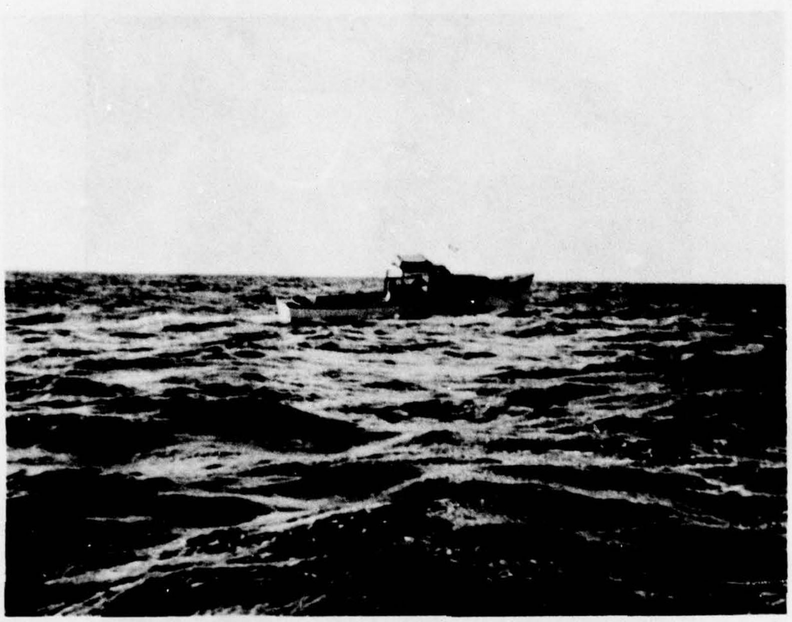
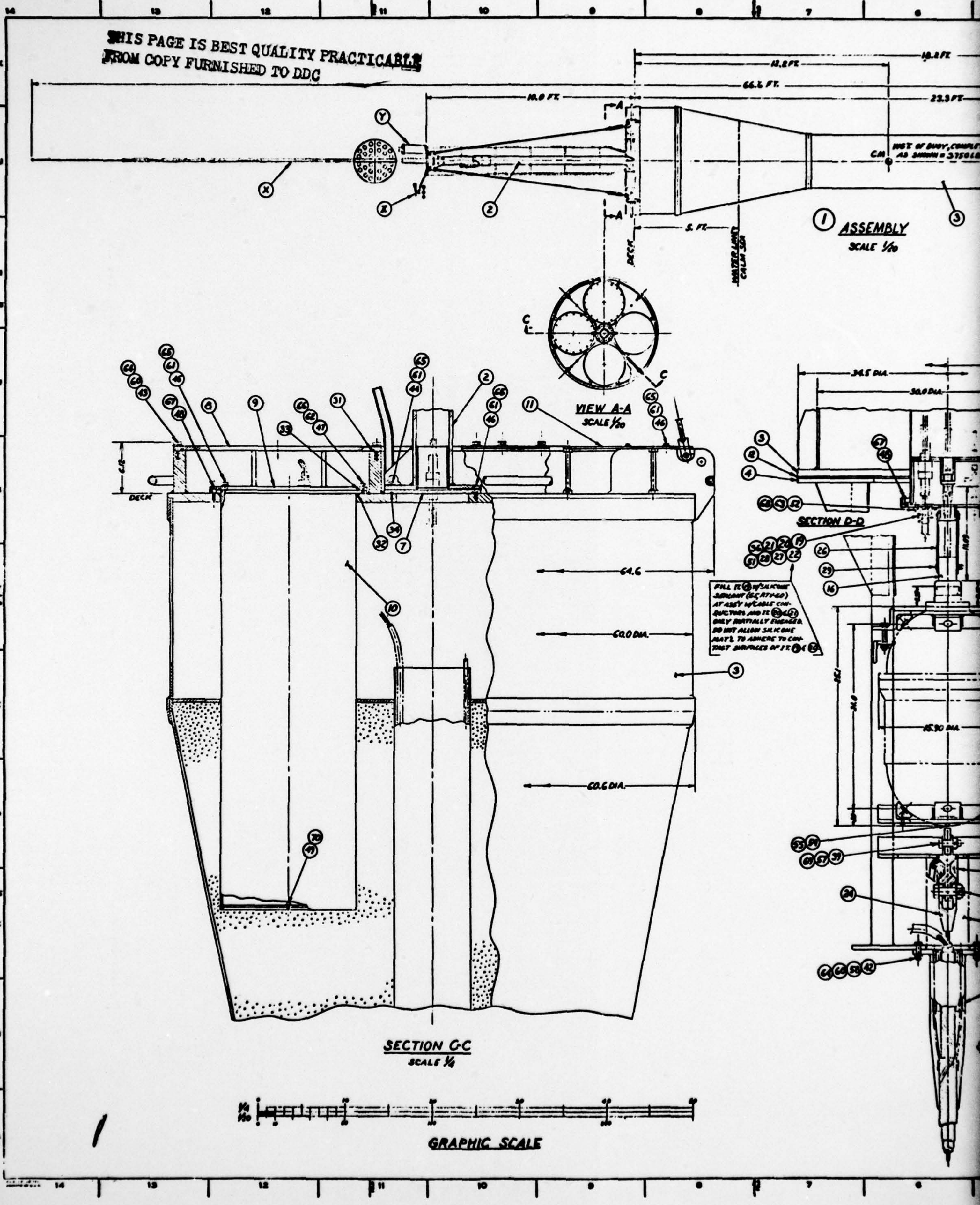
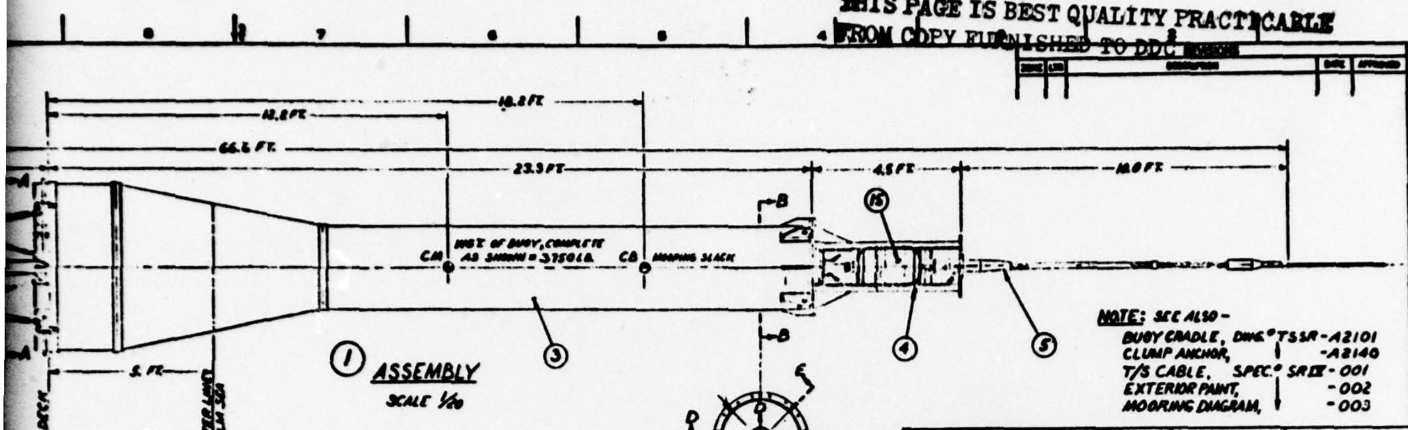
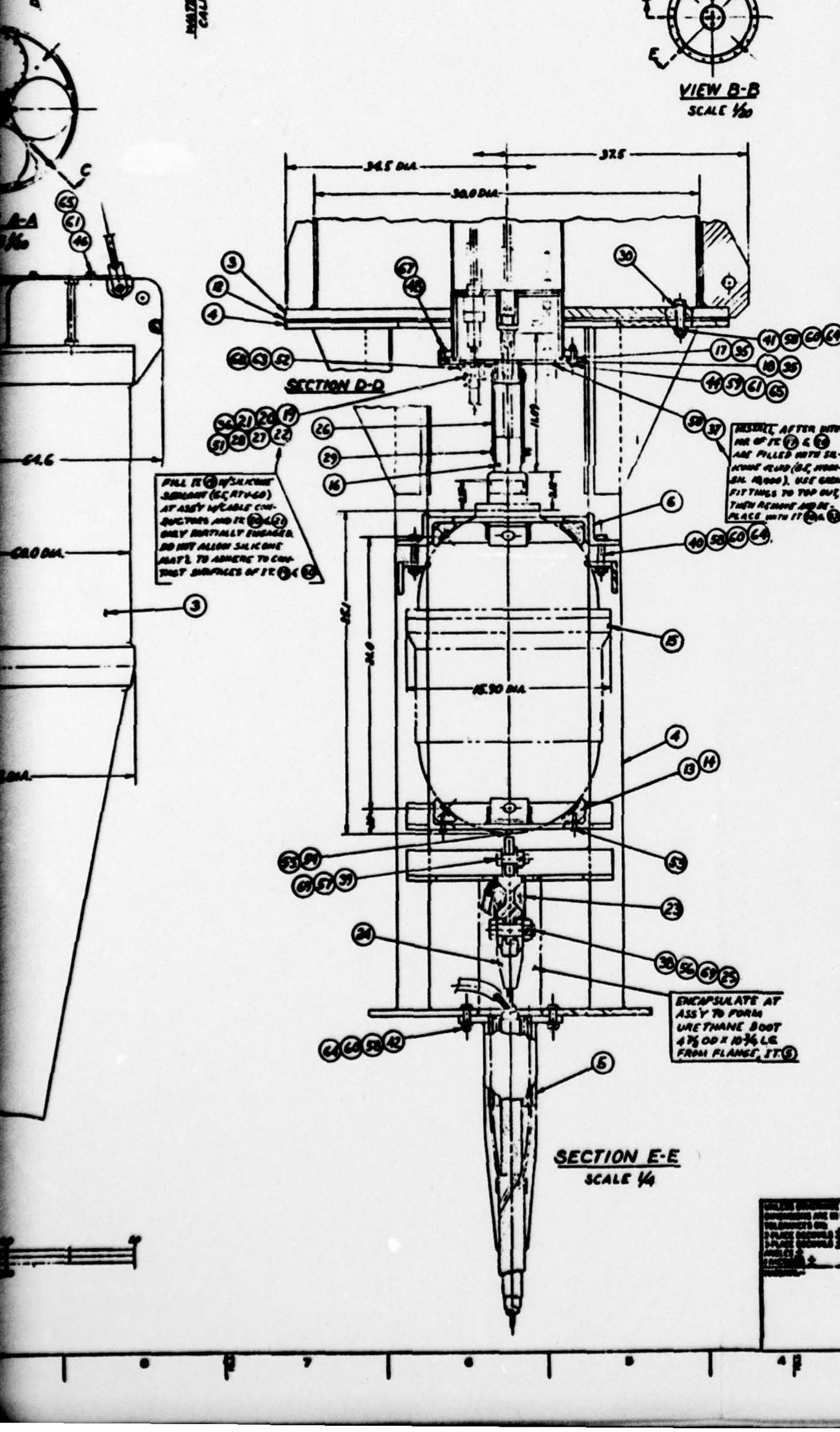


Figure A-26 The R.V. Rosette Used For The Implant And For Bathymetry.


10.0 FT.
12.2 FT.
66.6 FT.
18.8 FT.
22.3 FT.
C.M.
WGT. OF BUOY, COMPLETE AS SHOWN = 37500 LB.
5. FT.
DECK
WATER LINE CALM SEA
ASSEMBLY
SCALE 1/20
VIEW A-A
SCALE 1/20
34.5 DIA.
30.0 DIA.
SECTION D-D
64.6
60.0 DIA.
60.6 DIA.
15.90 DIA.
FILL ITEM W/ SILICONE SEALANT AT ASSY W/ CABLE CONDUCTORS AND ITEM ONLY PARTIALLY ENGAGED. DO NOT ALLOW SILICONE MAT'L TO ADHERE TO CONTACT SURFACES OF IT.
SECTION C-C
SCALE 1/4
GRAPHIC SCALE



NOTE: SEE ALSO -
BUOY CRADLE, DWG.° TSSR-A2101
CLUMP ANCHOR, -A2140
T/S CABLE, SPEC.° SR IV-001
EXTERIOR PAINT, -002
MOORING DIAGRAM, -003



GRP	GRP	ITEM	IDENTIFICATION	DESCRIPTION	MAT'L or REF. NOTES
	1	Z	MET. PKG	DISCRETIONARY EQUIP.	
	1	Y	NAV-LITE	REF. ON-BOARD	
	1	X	ANTENNA ASSY	ELECTRONICS SPEC.	[illegible]
	4	70	SEAL	1/2 OD x 1/4 ID x 1/16 THK	SILICONE RBR., 70 DUR.
	2	69	PIN, COTTER	3/16 x 2. LG.	MONEL
	24	68	WASHER, FLAT	°10	STAINLESS STL
	34	67	WASHER, FLAT	1/4	
	16	66	WASHER, FLAT	5/16	
	60	65	WASHER, FLAT	3/8	
	120	64	WASHER, FLAT	1/2	
	24	63	WASHER, LK HEL. SPR.	°10	
	16	62	WASHER, LK HEL. SPR.	5/16	
	48	61	WASHER, LK HEL. SPR.	3/8	
	92	60	WASHER, LK HEL. SPR.	1/2	
	12	59	NUT, HEX.	3/8 - 16UNC	
	28	58	NUT, HEX.	1/2 - 13UNC	
	1	57	NUT, HEX.	3/4 - 10UNC	MONEL
	1	56	NUT, HEX.	7/8 - 9UNC	
	2	55	NUT, HEX.	1/4 - 20UNC	NYLON
	2	54	STUD	1/4 - 20UNC x 1 1/4 LG.	
	6	53	SCREW, FIL. HD.	1/4 - 20UNC x 1. LG.	
	24	52	SCREW, HEX HD	°10 - 24UNC x 1/2 LG.	STAINLESS STL
	4	51	SCREW, PAN HD.	°10 - 24UNC x 5/16 LG.	
	4	50	SCREW, PAN HD.	1/4 - 28UNF x 1/2 LG.	
	4	49	BOLT, SOC. HD.	1/4 - 20UNC x 1/2 LG.	
	34	48	BOLT, SOC. HD.	1/4 - 20UNC x 3/4 LG.	
	16	47	BOLT, HEX. HD.	5/16 - 18UNC x 3/4 LG.	
	12	46	BOLT, HEX. HD.	3/8 - 16UNC x 1 1/4 LG.	
	16	45	BOLT, HEX. HD.	3/8 - 16UNC x 1 1/2 LG.	
	20	44	BOLT, HEX. HD.	3/8 - 16UNC x 1 3/4 LG.	
	64	43	BOLT, HEX. HD.	1/2 - 13UNC x 1 1/2 LG.	
	8	42	BOLT, HEX. HD.	1/2 - 13UNC x 2. LG.	
	16	41	BOLT, HEX. HD.	1/2 - 13UNC x 2 1/2 LG.	
	4	40	BOLT, HEX. HD.	1/2 - 13UNC x 2 3/4 LG.	
	1	39	BOLT, HEX. HD.	3/4 - 10UNC x 2 1/2 LG.	MONEL
	1	38	BOLT, HEX. HD.	7/8 - 9UNC x 3 LG.	
	4	37	O-RING	-010	BUNA-N, 70 DUR.
	4	36	O-RING	-128	
	2	35	O-RING	-270	
	1	34	O-RING	-371	
	4	33	O-RING	-384	
	4	32	O-RING	-460	
	4	31	O-RING	-470	
	16	30	ISOLATOR, BOLT	TSSR-D2091, IT. 4	
	2	29	CLAMP, HOSE	IDEAL HY-GEAR 5336 [illegible]	STAINLESS STL
	4	28	CLAMP, HOSE	IDEAL MICRO-GEAR 6208 [illegible]	
	4	27	TUBING	5/8 ID x 1/16 WALL x 72 LG.	VINYL
	1	26	TUBE	2. ID x 1/4 WALL x 7 LG.	TYGON B44-3
	2	25	SPACER	1 3/8 OD x 9/16 ID x 1/8 THK	NYLON
	1	24	CONNECTION	[illegible]	GALV. STL [illegible]
	1	23	TENSIOMETER	TSSR-B2092	[illegible]
	4	22	WASHER	TSSR-E2060, IT. 12	
	4	21	PLUG	TSSR-E2060, IT. 11	
	4	20	RETAINER	TSSR-E2060, IT. 10	
	4	19	FEED-THRU, CABLE	TSSR-E2060, IT. 9	
	1	18	COVER, CON. BOX	TSSR-E2060, IT. 6	
	1	17	BOX, CONNECTOR	TSSR-E2060, IT. 1	
	1	16	CONNECTOR, RPG	[illegible]	[illegible]
	1	15	RPG, SNAP-21	NWPU - FT. BELVOIR, VA	BERYLCO 165
	AR	14	SHIM, RPG ISOL.	TSSR-D2091, IT. 6	
	8	13	ISOLATOR, RPG	TSSR-D2091, IT. 1	
	1	12	ISOLATOR, FRAME	TSSR-D2091, IT. 5	
	4	11	STEP-PLATE	TSSR-B2051	
	4	10	CANISTER, INST.	TSSR-C2070	
	4	9	COVER, INST CAN	TSSR-D2050, IT. 5/6	
	4	8	COVER, HATCH	TSSR-D2050, IT. 1	
	1	7	PLATE, MAST	TSSR-D2050, IT. 4	
	1	6	HOLD-DOWN	TSSR-E2090, IT. 12	
	1	5	FAIRLEAD	PREFORMED LINE PRODUCTS [illegible]	GALV. STEEL
	1	4	FRAME	TSSR-E2090, IT. 1	
	1	3	HULL	TSSR-E2040	
	1	2	MAST	TSSR-D2030	
	X	1	ASSEMBLY		

GENERAL ELECTRIC

BUOY ASSEMBLY

SEA ROBIN IV

E

TSSR-E2000

TSSR-E2000

2

APPENDIX B

DESCRIPTION OF PROCESSED DATA ON MAGNETIC TAPE

The final form of the data taken from the Sea Robin IV Buoy system after editing and processing was written onto a magnetic tape. The original form of this tape is 7 track with a data density of 800 bits per inch. A copy was made and delivered to the scientific officer, which is 9 track with a density of 800 bits per inch which is now a more standard format.

In order to facilitate future analysis of the data, a small FORTRAN program is given in Table B-1 that reads the data off the tape. This program denotes the order in which the data was written and the formats used. This tape has a header label consisting of its name, "SRTOT", followed by an end of file symbol. The data follows next in the order specified in the program. The output from this program is presented in Table B-2. It consists of the first three blocks of data printed in the same order as it was recorded on the tape. At the bottom of this printout is the number of blocks of data on the tape and the final time. The measured and derived parameters as described in Sections 3.2 and 3.3 are defined in Table B-3.

TABLE B-1. PROGRAM FOR READING SEA ROBIN IV DATA TAPE

```
C       SEA  ROBIN  IV  DATA  TAPE  READ  OUT
      DIMENSION EP(4),ITN(3),TM(19),ZA(19),TC(19),CC(19),Z(13)
C      READ  TAPE
    1 READ(1,5,END=8) NB,DT,IWV,IWD,EP,ITN
      READ(1,10) TM
      READ(1,15) ZA
      READ(1,10) TC
      READ(1,15) CC
      READ(1,15) Z
      READ(1,16)
C       WRITE  FIRST  3  BLOCKS
      IF(NB.LE.3) WRITE(6,20) NB,DT,IWV,IWD,EP,ITN
      IF(NB.LE.3) WRITE(6,30) TM,ZA,TC,CC,Z
      GO TO 1
    8 WRITE (6,40) NB,DT
      STOP
    5 FORMAT(I6,F8.3,2I4,4F7.2,3I6)
   10 FORMAT((6X,10F7.2))
   15 FORMAT((6X,10F8.2))
   16 FORMAT(1H )
   20 FORMAT(///4X,"NB",4X,"DT",4X,"IWV"," IWD"," EP(1)","  EP(2)",
     &  "  EP(3)","  EP(4)"," ITN(1)"," INT(2)",3X,"ITN(3)"/
     &  I6,F8.3,2I4,4F7.2,3I6)
   30 FORMAT(//8X,"TM(1-19) =",10F8.2/18X,9F8.2/8X,"ZA(1-19) =",
     &  10F8.2/18X,9F8.2/8X,"TC(1-19) =",10F8.2/18X,9F8.2/8X,
     &  "CC(1-19) =",10F8.2/18X,9F8.2/8X," Z(1-13) =",10F8.2/18X,
     &  3F8.2)
   40 FORMAT(///5X,I6,2X,"BLOCKS OF DATA ON THIS TAPE"
     &  5X,"FINAL DT =",F8.3)
      END
```

TABLE B-2. OUTPUT FROM TAPE READING PROGRAM

```
NB    DT     IWV IWD EP(1)   EP(2)   EP(3)   EP(4) ITN(1) INT(2) ITN(3)
 1  15.957    0   9  27.15   10.00   10.00   28.82  1592   1592      0

   TM(1-19) =    25.40    23.44    21.26    19.68    19.51    18.11    16.45    14.50    12.21     9.88
                  8.62     7.24     6.55     6.42     6.01     5.63     5.43     5.14     4.12
   ZA(1-19) =     7.00    99.86   149.75   199.62   249.48   349.16   448.79   548.38   647.95   747.48
                846.98   946.45  1001.15  1045.90  1095.62  1145.33  1195.03  1244.73  1483.22
   TC(1-19) =    25.40    23.44    21.25    19.67    19.50    18.10    16.43    14.47    12.16     9.83
                  8.57     7.20     6.51     6.39     5.98     5.60     5.41     5.12     4.10
   CC(1-19) =  1497.41  1493.35  1487.62  1525.61  1525.99  1523.62  1520.17  1515.47  1509.25  1502.42
               1499.30  1495.61  1493.85  1494.11  1493.34  1492.67  1492.72  1492.40  1492.27
    Z(1-13) =   142.56   218.92   201.01   341.86   480.73   574.85   687.76   758.53   876.89   933.65
               1102.83  1225.57  1464.00

NB    DT     IWV IWD EP(1)   EP(2)   EP(3)   EP(4) ITN(1) INT(2) ITN(3)
 2  15.967    0   9  27.15   10.00   10.00   28.44  1281   1558     33

   TM(1-19) =    25.27    23.46    21.23    19.68    19.59    18.16    16.48    14.43    12.03     9.90
                  8.64     7.24     6.51     6.34     6.03     5.63     5.41     5.14     4.12
   ZA(1-19) =     7.00    99.89   149.80   199.70   249.59   349.33   449.04   548.72   648.37   748.00
                847.61   947.19  1001.96  1046.76  1096.53  1146.30  1196.07  1245.83  1484.63
   TC(1-19) =    25.27    23.46    21.22    19.67    19.59    18.15    16.46    14.40    11.99     9.86
                  8.60     7.21     6.48     6.32     6.01     5.61     5.39     5.12     4.10
   CC(1-19) =  1497.04  1493.41  1487.54  1525.62  1526.22  1523.77  1520.28  1515.26  1508.64  1502.53
               1499.42  1495.64  1493.72  1493.82  1493.44  1492.69  1492.66  1492.42  1492.29
    Z(1-13) =   143.39   218.84   193.14   337.60   478.87   577.76   695.46   757.00   875.00   932.90
               1098.82  1224.47  1462.58

NB    DT     IWV IWD EP(1)   EP(2)   EP(3)   EP(4) ITN(1) INT(2) ITN(3)
 3  15.977    0   9  27.15   10.00   10.00   28.12  1592   1558     33

   TM(1-19) =    25.35    23.50    21.20    19.67    19.59    18.14    16.48    14.48    12.14     9.97
                  8.66     7.26     6.51     6.37     6.03     5.65     5.41     5.14     4.09
   ZA(1-19) =     7.00    99.89   149.80   199.70   249.59   349.33   449.03   548.71   648.36   747.98
                847.58   947.17  1001.93  1046.73  1096.50  1146.27  1196.03  1245.79  1484.58
   TC(1-19) =    25.35    23.50    21.19    19.66    19.59    18.13    16.46    14.45    12.10     9.93
                  8.62     7.23     6.48     6.34     6.01     5.63     5.39     5.12     4.07
   CC(1-19) =  1497.27  1493.53  1487.44  1525.59  1526.22  1523.71  1520.28  1515.43  1509.03  1502.79
               1499.50  1495.72  1493.72  1493.94  1493.44  1492.77  1492.66  1492.42  1492.16
    Z(1-13) =   144.28   219.42   193.14   339.24   478.88   575.45   690.51   753.52   873.77   931.27
               1098.85  1224.51  1470.83

4058  BLOCKS OF DATA ON THIS TAPE     FINAL DT =  54.280
```

TABLE B-3. SEA ROBIN IV REDUCED DATA

Variable	Definition
NB	Block sequence number
DT	Time, days since 1 Jan 76
IWV	Wind velocity, knots
IWD	Wind direction (compass point):

1 = N	5 = E	9 = S	13 = W
2 = NNE	6 = ESE	10 = SSW	14 = WNW
3 = NE	7 = SE	11 = SW	15 = NW
4 = ENE	8 = SSE	12 = WSW	16 = NNW

Variable	Definition
EP(1)	Atmospheric pressure, in. Hg
EP(2)	Van internal temperature, ^{o}F
EP(3)	Van external temperature, ^{o}F
EP(4)	Buoy surface temperature, ^{o}C
ITN(1)	Mooring line tension, lbs.
ITN(2)	Mooring line tensions averaged over the 9 previous points, lbs.
ITN(3)	Sea state parameter (RMS of tension), lbs.
TM(1) $\rightarrow$ TM(19)	Measured temperature starting at the surface and in descending depths, ^{o}C
ZA(1) $\rightarrow$ ZA(19)	Adjusted thermistor depths, m
TC(1) $\rightarrow$ TC(19)	Corrected temperatures at the adjusted depths, ^{o}C
CC(1) $\rightarrow$ CC(19)	Computed sound speeds at the adjusted depths, m/sec
Z(1) $\rightarrow$ Z(13)	Isotherm depths, m, for the following temperatures: T(1) = 21, 20, 19, 18, 17, 15, 13, 10, 9, 7, 6, 5, $4^{o}C$ = T(13)

UNCLASSIFIED

DISTRIBUTION LIST

Office of Naval Research 800 N. Quincy Street Arlington, Virginia 22217 Attn: Code 222 1020S 480	 2 1 1
Director Naval Research Laboratory 4555 Overlook Avenue S.W. Washington, D.C. 20375	 6
Director Office of Naval Research Branch Office 1030 East Green Street Pasadena, California 91106	 1
Office of Naval Research San Francisco Area Office 760 Market Street Room 447 San Francisco, California 94102	 1
Director Office of Naval Research Branch Office 495 Summer Street Boston, Massachusetts 02210	 1
Office of Naval Research New York Area Office 207 West 24th Street New York, New York 10011	 1
Commanding Officer Office of Naval Research Branch Office Box 39 FPO New York 09510	 1
Director Office of Naval Research Branch Office 536 South Clark Street Chicago, Illinois 60605	 1
Commander Naval Surface Weapons Center Acoustics Division Silver Spring, Maryland 20910 Attn: Dr. Zaka Slawsky	 1

Officer in Charge
Naval Ship Research & Development Center
Annapolis Laboratory
Annapolis, Maryland 21402 — 1

Commander
Naval Sea Systems Command
National Center #2
2521 Jefferson Davis Highway
Arlington, Virginia 20360
Attn: SEA 037 — 1
Carey Smith, 06H1 — 1
David F. Bolka, 06H2 — 1

Commanding Officer
Fleet Numerical Weather Center
Monterey, California 93940 — 1

Defense Documentation Center
Cameron Station
Alexandria, Virginia 22314 — 12

Director of Navy Laboratories
Chief of Naval Material
2211 Jefferson Davis Highway
Crystal Plaza #5
Arlington, Virginia 20360
Attn: Dr. James Probus, MAT 03L — 1

Commander
Naval Electronic Systems Command
2511 Jefferson Davis Highway
National Center #1
Arlington, Virginia 20360 — 1
Attn: CDR A. R. Miller, ELEX 320

Commander
Naval Ship Research & Development Center
Department of the Navy
Bethesda, Maryland 20084
Attn: Mr. Craig Olson — 1
Unclassified Library — 1

Chief of Naval Operations
Room 4D518, Pentagon
Washington, D.C. 20350
Attn: CAPT A. H. Gilmore — 1

Commander
Naval Ocean Systems Center
Department of the Navy
San Diego, California 92132
Attn: Dr. Dan Andrews — 1
Dr. Dean Hanna — 1
Mr. Henry Aurand — 1

Superintendent
Naval Research Laboratory
Underwater Sound Reference Division
P.O. Box 8337
Orlando, Florida 32806 — 1

Commanding Officer
Naval Underwater Systems Center
New London Laboratory
New London, Connecticut 06320
Attn: Dr. A. Nuttall — 1
Mr. A. Ellinthorpe — 1
Dr. D. M. Viccione — 1

Commander
Naval Air Development Center
Department of the Navy
Warminster, Pennsylvania 18974
Attn: Unclassified Library — 1

Superintendent
Naval Postgraduate School
Monterey, California 93940
Attn: Unclassified Library — 1

Commanding Officer
Naval Coastal Systems Laboratory
Panama City, Florida 32401
Attn: Unclassified Library — 1

Commanding Officer
Naval Underwater Systems Center
Newport Laboratory
Newport, Rhode Island 02840
Attn: Unclassified Library — 1

Superintendent
U.S. Naval Academy
Annapolis, Maryland 21402
Attn: Library — 1

Commanding Officer
Naval Intelligence Support Center
4301 Suitland Road
Suitland, Maryland 20390
Attn: Dr. Johann Martinek — 1
Mr. E. Bissett — 1

Commander
Naval Sea Systems Command
Washington, D.C. 20362
Attn: Unclassified Library, SEA 03E — 1

Special Assistant for ASW
Office of the Assistant Secretary of
the Navy for Research, Engineering & Systems
Washington, D.C. 20350
Attn: Dr. D. Hyde 1

Dr. Melvin J. Jacobson
Rennselear Polytechnic Institute
Troy, New York 12181 1

Dr. T. G. Birdsall
Cooley Electronics Laboratory
University of Michigan
Ann Arbor, Michigan 48105 1

Dr. Harry DeFerrari
University of Miami
Rosentiel School of Marine & Atmospheric Sciences
4600 Rickenbacker Causeway
Miami, Florida 33149 1

Dr. M. A. Basin
S.D.P. Inc.
15250 Ventura Boulevard
Suite 518
Sherman Oaks, California 91403 1

Dr. Walter Duing
University of Miami
Rosentiel School of Marine & Atmospheric Sciences
4600 Rickenbacker Causeway
Miami, Florida 33149 1

Dr. David Middleton
127 East 91st Street
New York, New York 10028 1

Dr. Donald Tufts
University of Rhode Island
Kingston, Rhode Island 02881 1

Dr. Loren Nolte
Duke University
Department of Electrical Engineering
Durham, North Carolina 27706 1

Mr. S. W. Autrey
Hughes Aircraft Company
P.O. Box 3310
Fullerton, California 92634 1

Dr. Thomas W. Ellis
Texas Instruments, Inc
13500 North Central Expressway
Dallas, Texas 75231 — 1

Dr. Terry Ewart
Applied Physics Laboratory
University of Washington
1013 Northeast Fortieth Street
Seattle, Washington 98195 — 1

Institute for Acoustical Research
Miami Division of the Palisades Geophysical Institute
615 S.W. 2nd Avenue
Miami, Florida 33130 — 2
Attn: Mr. M. Kronengold
Dr. J. Clark
Dr. W. Jobst
Dr. S. Adams

Mr. Carl Hartdegen
Palisades Sofar Station
Bermuda Division of Palisades Geophysical Institute
FPO New York 09560 — 1

Mr. Beaumont Buck
Polar Research Laboratory
123 Santa Barbara Avenue
Santa Barbara, California 93101 — 1

Dr. M. Weinstein
Underwater Systems, Inc
8121 Georgia Avenue
Silver Spring, Maryland 20910 — 1

Dr. Thomas G. Kincaid
General Electric Company
P.O. Box 1088
Schenectady, New York 12301 — 1

Applied Research Laboratories
University of Texas at Austin
P.O. Box 8029
10000 FM Road 1325
Austin, Texas 78712
Attn: Dr. Lloyd Hampton — 1
Dr. Charles Wood — 1

Dr. C. N. K. Mooers
University of Delaware
Newark, Delaware 19711 — 1

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
Attn: Dr. Paul McElroy 1
Dr. R. Porter
Dr. R. Spindel

Dr. John Bouyoucos
Hydroacoustics, Inc
321 Northland Avenue
P.O. Box 3818
Rochester, New York 14610 1

Atlantic Oceanographic & Meteorological Laboratories
15 Rickenbacker Causeway
Miami, Florida 33149
Attn: Dr. John Proni 1